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Cover illustration: Thin sections of several different habits of barite. Photographs: Jane Clarke.

Botryoidal barite Mag 538; ppl.	Acicular barite Mag 549; xpl.	Poikilotopic barite Mag 530; xpl.
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Irish dendrochronology and weird stuff

Professor M G L Baillie, Palaeoecology Centre, School of Archaeology and Palaeoecology, Queen's University, Belfast

Most people are familiar with dendrochronology, though there can be an unfortunate tendency to think of it in terms of "counting rings" - every child knows that it is possible to tell the age of a tree by counting its growth rings. In fact there is much more to this subject than simple ring counting, and the last thirty years have witnessed the emergence of a whole scientific discipline with many dating and environmental applications. I am going to take the reader on a brief excursion into the experience gained by tree-ring workers in Ireland in order to set the scene for a discussion on possible comet hazards.

Back in the 1960s workers in the USA had built an 8000 year record of bristlecone pine ring widths (Ferguson 1969). Hans Suess, a specialist in radiocarbon dating, had then used precisely dated samples of wood from the chronology in order to calibrate the radiocarbon timescale (Suess 1970). The calibration curve that Suess produced gave rise to two areas of controversy. Suess's calibration results showed both a long secular deviation from the theoretically expected straight line relationship between radiocarbon years and real years, and short term departures which Suess christened "wiggles". The debates centred around whether or not the wiggles were real (some said they were simply statistical noise while Suess maintained that they were really there in the data) and whether the long secular departure was universal or merely applicable to samples from the high-altitude, western American bristlecone samples. As a result of this double controversy it was decided to attempt to build a long tree-ring chronology in Ireland, using oak timbers, in order to re-calibrate radiocarbon using low-altitude, Old World, tree-ring samples.

So, around 1970, with purely scientific motives we started to build long sections of well replicated tree-ring chronology. Obviously the first section was composed of living and recently felled oaks. We determined that we could indeed cross date the patterns of wide and narrow rings from one tree to another. We produced a computer program which would slide one ring pattern past another, moving one year at a time, and calculate a correlation coefficient at every possible position of overlap. We ascertained that the computer could pick out the correct matching positions, something humans could do very well by examining superimposed graphs of the tree-ring patterns. With this statistical backup we made a master chronology of some thirty Irish oaks. That chronology ran back to the middle of the seventeenth century. Next we constructed a 337-year floating chronology made up from the ring patterns of oak timbers from several buildings of the seventeenth and eighteenth centuries. Successful overlapping of the modern chronology with this floating medieval chronology showed that the floating chronology actually spanned 1380 to 1716. Two more similar exercises using composite site chronologies took us back first to 919 and then, using a long series from archaeological excavations in Dublin, back to AD 855. After that it was simply a matter of working further and further back in time using more and more ancient archaeological assemblages and, importantly, the huge number of naturally preserved sub-fossil oaks from the Irish peat bogs. By the early 1980s we had a continuous, year by year record of what oaks thought of their growth conditions for every year back to 5289 BC.

From a scientific viewpoint the most incredible thing about this exercise was that it turned out we were not alone - colleagues in Germany had also built long oak chronologies. This was vitally important because, by 1984, we were able to demonstrate that the Irish and German tree-ring chronologies were in precise synchronization back for 7000 years. We could do this by observing that we could each date sections of floating English oak chronology to exactly the same year, whether they were dated against the German or the Irish chronology. So by 1984 we could demonstrate a fully replicated set of tree-ring chronologies, with calendar precision, for western Europe. One outcome of this was a replicated radiocarbon calibration curve carried out in Ireland by Pearson and, using German oak, by Stuiver in America (Stuiver & Pearson 1993). The outcome was that Suess's long term secular variation, and his short term wiggles, were vindicated; although the more precise modern measurements meant that the Stuiver and Pearson calibration replaced that of Suess.

From an archaeological standpoint, the existence of the long oak chronologies (we built another chronology in England which runs back to 4989 BC) meant that we could offer a commercial dating service for oak timbers from archaeological sites and buildings. The result of this dating has been to inject a whole series of precise dates into Irish, British, German and Swiss prehistory. Other chronologies of similar length are coming on line from France, Finland, Sweden, Siberia and the Aegean. All of this offers the prospect of a precisely dated framework for archaeological research across Europe and beyond.

Such is the background to European dendrochronology seen from an Irish perspective. Let me just take a moment to drive home the significance of what dendrochronologists have done.

Pick a year, any year, in the last 7000 years - let us say 3456 BC. We can now tell you what oak trees thought of their growth conditions in that year compared with the years before and after. We can do that for Ireland; indeed we can do it for several different sites in Ireland. We can then compare with oaks which grew in exactly the same year - 3456 BC - in western and in eastern England. We can look at oak growth for the same year in several German and Swiss sites. So, we can actually plot contours of oak response across Europe for that, or any other, year. If you happen to be a research chemist we can select out a sample of cellulose which grew in that same year and you can analyse it for trace elements or for stable isotopes. For the same year, you can analyse samples from different trees, from different sites, from different countries.

This last paragraph acts as a useful introduction to the environmental story. It raises the concept of comparing tree-ring chronologies from different areas to see if there are any similarities in response. It turns out that when you do this, some interesting events appear. However, to see how the story developed we have to go back to those Irish oaks and the oak chronology.

The tree-ring events

In the late 1980s a series of 'narrowest ring' events were discovered in the long, Irish, oak, tree-ring sequence (Baillie & Munro 1988). What made these events apparently significant was their spaced occurrence very close to the dates for significant acid layers in the Greenland ice cores from Camp Century and Dye 3 (Hammer *et al*. 1980; 1987). The dates included 2345 BC, 1628 BC, 1159 BC, 207 BC and 540 AD with a hint of something similar in 44 BC. These dates were termed 'marker dates' because around the time they were discovered other workers such as Pang and colleagues (1985; 1988) pointed out the similarity of the second millennium dates to the dates for the withdrawal of the 'Mandate of Heaven' from the Chinese emperors Chieh and Chou at the end of the Xia and Shang dynasties respectively. Pang *et al*. (1985,1988) pointed out that there were dust-veil-like descriptions associated with the dynastic downfalls. In addition they drew attention to catastrophic happenings in China close to the start of the Han dynasty in 206 BC, and in the late AD 530s. Frost rings in bristlecone pine records from California were observed in 1627 BC, 206 BC and 43 BC (LaMarche & Hirschboeck 1984; Baillie 1995), while it was notable that the Justinian plague broke out in AD 542. Readers will obviously be asking why volcano induced environmental downturns are in any way relevant to a discussion of cometary hazards. The possible relevance comes from a strange circumstantial story of which a paraphrase is given below.

The comet story

In 1983 Stothers & Rampino had drawn attention to a major 'dry fog' in the year AD 536 recorded in Mediterranean histories. This was believed to be a volcanic dust veil, probably the most severe dust veil in the last two millennia (Stothers 1984). The problem was that in the Irish tree-rings, indeed in European oaks taken as a group, although the growth ring for AD 536 was notably reduced, a much more severe growth reduction took place across AD 540; an event also evident in other chronologies from around the world. Ice core evidence available up to 1997 showed no good evidence for a volcanic acid signal in the time window AD 536-545. This raised the issue of whether the environmental effects might be due to some cause other than volcanism (Baillie 1995). In my view, if volcanism is set aside, the next most likely cause of a global atmospheric loading would be due to airbursts associated with Tunguska-class impacts from space. It turned out that this idea is exactly consistent with a hypothesis put forward by Bailey, Clube & Napier in 1990 suggesting that the earth was at increased risk of bombardment in the time window AD 400 to 600. This suggestion was based on the large number of major meteor showers in the period.

Thus, by 1994 the possibility was being considered that there might have been a catastrophic bombardment event around AD 540. When the following observations are included, a quite surprising scenario looms:

44 BC. A red daylight comet is seen in the year of Caesar's death

207 BC. Livy records showers of stones in a number of years between 220 BC and 190 BC; however, the real significance of his record is that in 205 BC the goddess Cybele is brought back to Rome at the behest of the Sibylline Books specifically because of the repeated showers of stones from the sky (Forsyth 1990). As Cybele was herself a small black meteorite, we can take it that stones really were falling from the sky around this time.

circa 1159 BC. The twelfth century is proximate to the fall of the Shang dynasty. A comet is recorded in the year of Chòu's defeat by Wu Wang. According to Sagan and Druyan (1985) this is the second documented record of a comet.

circa 1628 BC. The seventeenth century BC is proximate to the fall of the Xia dynasty. A comet is recorded in the year of Chieh's defeat by T'ang. According to Sagan and Druyan this is the first documented record of a comet.

circa 2345 BC. Newton & Halley accepted Usher's 2348 BC date for the biblical Flood. Newton showed that comets were physical bodies obeying the same physical laws as planets; however, both continued to believe that comets were God's instruments for ultimate change. As Schechner Genuth puts it:

> "Given the roles comets might play in the Apocalypse, it is not surprising that Newton considered the role one might have played in the Flood. Gregory tersely recounted Newton's idea that "a comet passing near the Earth to the east has altered its course in perihelium just as the Moon by attracting the waters caused a deluge" ... (and) ... To Gregory, Conduitt, and Halley, Newton intimated that comets were divine agents destined to reconstitute the entire solar system, to prepare sites for new creations and to usher in the Millennium ... (while) ... With a firm belief that God acted through natural causes, Halley sought a physical cause for the deluge (1997; 151-153, 162)."

Thus both Newton and Halley, having understood the nature of cometary orbits, recognised that the Earth could be hit; that it had probably been hit in the past and would undoubtedly be hit in the future. This makes it interesting that both believed that the biblical Flood had been due to a comet coming close to the Earth.

This list might explain the ancient notion that comets were seen to signal the death of kings. If comets were in the popular imagination associated with the death of kings that was because comets had brought about the death of kings in the past. How could these remote entities actually affect kings on Earth? Most likely, if a comet came close enough to the Earth for fragments to impact (and thus load the atmosphere with a dust veil) or for significant amounts of associated dust/volatiles to load the atmosphere directly, then the logic chain would be as follows:

A cometary dust veil produces cooling (just as a volcanic dust-veil but quite possibly on a truly global scale). The cooling leads to crop failures and famines with, quite possibly, plague as a consequence. Under these circumstances kings, who often reigned with a 'mandate of heaven', would be seen to have fallen from divine grace and would be swept aside in the political turmoil following the apparition of the comet-induced trauma.

If impacting fragments were involved, with fireballs, megaton-class explosions in the atmosphere and earthquakes, the events would be memorable in the extreme. So, it is possible to outline an entirely plausible scenario wherein popular tradition might have associated the death of kings with comets.

This story would be almost laughable were it not for some additional information. It turns out that mythology, and some early history, provides loose links between the centuries of these events and associates them with bright sky gods. For example, the Greek

god Apollo who is the divine archer traditionally brings plague to Troy in the 12th century BC. But Apollo slays the monster Python, who originally crawled out of the slime left by the Flood (Fontenrose 1959). But Python is interchangeable with Typhon, a god of the Hyksos which clearly links to the 17th century BC; while Pliny refers to a comet called Typhon.

Once these links are noticed, they simply go on occurring. For example, in Britain Arthur traditionally dies in AD 542. Who is Arthur? It turns out that he is cognate with the Irish god/heroes such as Finn or CuChulainn. But CuChulainn is the re-birth of the god Lugh. Lugh is the bright Celtic god Lugh Lamfada, of the long reach, who comes up in the west as bright as the setting sun, with a long arm (Loomis 1927). Lugh sounds like a close comet.

We can link back to Arthur through the associated Grail legend, in which a blow from a lance (based on Lugh's fiery spear) causes a magic mist, an earthquake and gives rise to a 'wasteland'. Lugh is the Celtic Apollo.

With respect to the 207 BC tree-ring event, Cybele was manifest as a meteorite. She is recalled from Phrygia to save Rome in 205 BC. Burnt Phrygia is associated with a fire-breathing goddess who burns the forest as far as Syria (Fontenrose 1959). Courty (1997) reports an anomalous, possibly impact-related, petrographic assemblage from Syria which she dates to around 2350BC at the time of the Akkad. However, there is a late third millennium BC concept known as the "Curse of Akkad" which involves 'flaming potsherds that fall from the sky' and this is reinforced by an omen associated with the fall of the Akkad in which many stars were falling from the sky (Weiss 1996). Perhaps most surprising is the ancient Chinese story wherein, in the year 2346 "BC", the first emperor Yao meets the Divine Archer Shên I (clearly a version of Apollo). At the time there are terrible catastrophes including ten suns in the sky, famines, floods etc. The Divine Archer sets out to seek the cause of these catastrophic events and finds that they are due to the activities of one Fei Lien (a wind spirit) (Werner 1995).

Now, remembering the list of tree-ring dates, let us look at the associations of this story. In the Chinese stories Fei Lien, who was responsible for the calamities in the 24th century "BC" was also a minister of king Chòu. King Chòu is the last emperor of the Shang dynasty which ends traditionally in the 12th century "BC". Hence, preserved in a Chinese story is a link from the 24th to the 12th century BC.

Strangely, in China, in 2346 "BC", the Divine Archer is carrying a bow; while at the Flood (2349 "BC") God gives man a sign in the form of a bow. But the Greek Apollo shoots arrows at the time of Troy (traditionally 12th century "BC") while in China at the time of Chòu (traditionally 12th century "BC") one No-cha finds a wonderful bow and three magic arrows ... he shoots an arrow towards the southwest 'a red trail indicated the path of the arrow, which hissed as it flew' (a bolide description?). Subsequently it is observed that the arrow bears the description 'Arrow which shakes the heavens'.

This brief excursion into mythology shows a widespread imagery supplied with traditional dates which fall close to the dates of the environmental downturns observed in the tree-rings. While the case is a long way short of proven, the very existence of so many apparent links suggests that the story needs to be looked into quite seriously. If it were even partly true, then there exists a largely unsuspected hazard to civilisation.

This story poses the question whether Newton was privy to some ancient lore which explained the importance of comets in human history. In fact, is it possible that Newton's interest in comets was a response to a major contradiction. Newton knew that comets were real bodies obeying the same laws of motion as the planets and he could calculate their orbits; thus he was clearly aware that comets could strike the earth, and he may have been aware that they had done so. But he also knew that at the biblical Flood of 2349 "BC" God had said "I do set my bow in the cloud, and it shall be a token of a covenant between me and the earth … and the waters shall no more become a flood to destroy all flesh" (Genesis 9, 13-15). Was this the contradiction? We know that Newton was steeped in "Hermetic lore". It is probably significant that Hermes was one messenger of the gods, the other being Iris, the goddess of the Rainbow (Hamilton 1953). The real question of course is 'what else did Newton and Halley know?' and did their knowledge extend to the return times for some hazardous comet visitors?

[Note: the convention in this article is BC = calendar dates/archaeological dates; "BC" = quasi historical dates/annals.]

Bibliography

Bailey M E, Clube S V M & Napier W M, 1990, *The Origin of Comets*. Pergamon Press, London.

Baillie M G L, 1995, *A Slice Through Time: dendrochronology and precision dating*. Routledge, London.

Baillie M G L, 1998, Bronze Age myths expose archaeological shortcomings? a reply to Buckland *et al*. 1997. *Antiquity* **72**, 425-427.

Baillie M G L., 1999, *Exodus to Arthur: catastrophic encounters with comets.* Batsford, London.

Baillie M G L & Munro M A R, 1988, Irish tree-rings, Santorini and volcanic dust veils, *Nature* **332**, 344-6.

Buckland P C, Dugmore A J & Edwards K J, 1997, Bronze Age Myths? Volcanic activity and human response in the Mediterranean and North Atlantic regions. *Antiquity* **71**, 581-593.

Cavendish R, 1980, *King Arthur and The Grail*. Paladin, Granada Publishing, London.

Clube S V M & Napier B, 1990, *The Cosmic Winter*, Blackwell, Oxford.

Courty M-A, 1997, *Causes and Effects of the 2350 BC Middle East Anomaly Evidenced by Micro-Debris Fallout, Surface Combustion and Soil Explosion.* Abstract O-5 Second SIS Cambridge Conference Natural Catastrophes During Bronze Age Civilizations. Fitzwilliam College (11-13 July 1997).

Ferguson C W, 1969, A 7104-Year Annual Tree-Ring Chronology for Bristlecone Pine, Pinus Aristata, from the White Mountains, California, *Tree-Ring Bulletin* **29**, 2-29.

Fontenrose J, 1959, *Python: A Study of Delphic Myth and its Origins.* University of California Press, Berkeley.

Forsyth P Y, 1990, Call for Cybele, *The Ancient History Bulletin* **4.4**, 75-8.

Frazer J G, 1930, *The Golden Bough*. McMillan and Co. London.

Graves R, 1948, *The White Goddess*. Faber and Faber, London.

Hamilton E, 1953, *Mythology*. Mentor, New York.

Hammer C U, Clausen H B & Dansgaard W, 1980, Greenland Ice Sheet Evidence of Post-Glacial Volcanism and its Climatic Impact, *Nature* **288**, 230-5.

Hammer C U, Clausen H B, Friedrich W L & Tauber H, 1987, The Minoan Eruption of Santorini in Greece Dated to 1645 BC?, *Nature* **328**, 517-9.

Kuniholm P I, Kromer B, Manning S W, Newton M, Latini C E & Bruce M J, 1996, Anatolian tree rings and the absolute chronology of the eastern mediterranean, 2220-718 BC. *Nature* **381**, 780-783.

LaMarche V C Jr. & Hirschboeck K K, 1984, Frost Rings in Trees as Records of Major Volcanic Eruptions, *Nature* **307**, 121-6.

Levy D H, 1995, *The Quest for Comets.* Oxford University Press.

Lewis J S, 1996, *Rain of Iron and Ice: The very real threat of comet and asteroid bombardment.* Addison-Wesley, Reading, Massachusetts.

Loomis R S, 1927, *Celtic Myth and Arthurian Romance*. Columbia University Press, New York.

Pang K D & Chou H-H, 1985, Three Very Large Volcanic Eruptions in Antiquity and Their Effects on the Climate of the Ancient World, *EOS. Transactions, American Geophysical Union* **66**, 816.

Pang K D, Yau K, Chou H-H & Wolff R, 1988, Computer Analysis of Some Ancient Chinese Sunrise Eclipse Records to Determine the Earth's Rotation Rate. *Vistas in Astronomy* **31**, 833-847.

Sagan C & Druyan A, 1985, *Comet*. Michael Joseph, London.

Santillana G & Dechend H von, 1969, *Hamlet's Mill*. Macmillan, London.

Schechner Genuth S, 1997, *Comets, Popular Culture, and the Birth of Modern Cosmology*. Princeton University Press.

Steel D, 1995, *Rogue Asteroids and Doomsday Comets.* John Wiley and Sons, New York.

Stothers R B, 1984, Mystery Cloud of AD 536, *Nature* **307**, 344-5.

Stothers R B & Rampino M R, 1983, Volcanic Eruptions in the Mediterranean Before AD 630 From Written and Archaeological Sources, *Journal of Geophysical Research* **88**, 6357-71.

Strachey E, 1871, *Morte D'Arthur: Sir Thomas Malory's Book.* Macmillan, London.

Stuiver M & Pearson G W, 1993, High-Precision Bidecadal Calibration of the Radiocarbon Timescale, AD 1950 - 500 BC and 2500 BC- 6000 BC, *Radiocarbon* **35,** 1-23.

Suess H E, 1970, Bristlecone Pine Calibration of the Radiocarbon Timescale from 5200 BC to the Present, In: Olsson I U (ed.) *Radiocarbon Variations and Absolute Chronology*, John Wiley and Sons, New York, 303-9.

Verschuur G L, 1996, *Impact! The threat of comets and asteroids*. Oxford University Press, London.

Weiss H, 1996, In: Dalfes H N, Kukla G & Weiss H (eds), 1996, *Third Millennium BC Climate Change and Old World Collapse*. Springer-Verlag, Berlin.

Werner E T C, 1995, *Ancient Tales and Folklore of China.* Senate, London (originally published in 1922).

Wilson I, 1985, *The Exodus Enigma*. Guild Publishing, London.

Book reviews

The BIRPS Atlas II: A Second Decade of Deep Seismic Reflection Profiling by David Snyder and Richard Hobbs, 1999, The Geological Society, 3 CD ROMS £99 ISBN 1862390371.

This 3 CD set contains the results of a second decade of BIRPS deep seismic reflection profiling. The British Institutions Reflection Profiling Syndicate (BIRPS) was established by the NERC to use deep seismic reflection profiling to investigate the deep structure of the lithosphere beneath the British Isles. More than 50,000km of deep seismic reflection profile is now available to the world's geoscience community, representing the densest coverage of any area of comparable size in the world.

More recently the surveys have covered other interesting parts of the world and include the Baltic, Færoe-Iceland Ridge, Banda Arc, Chicxulub and West Africa. High standard marine seismic data form the majority of BIRPS surveys for two reasons - marine surveys are much more cost effective than those undertaken on land, and the economic requirement for hydrocarbon exploration offshore. There are numerous references for those who want more information on any particular site or methodology.

CD1 contains ten chapters of text and first class illustrations and diagrams describing surveys and research by thematic topics and would be of use to second and third level earth science students who wish to broaden, or deepen, their seismic studies. You will need Acrobat Reader software (supplied on the CD) which provides easy navigation on Windows (4Mb RAM), UNIX (8Mb RAM) or Mac (2Mb RAM).

CD2 and CD3 contain digital stacked sections (in SEG-Y format) with location details and you will need Win PICS seismic interpretation software (supplied on CD2) in order to work on any of the data you choose to copy to your hard disc. Minimum requirements – 100 MHz Pentium, 1 Gb hard disc space, 32 Mb RAM (64 Mb recommended). WinPICS will not run on Mac. These detailed sections will obviously be of most use to those undertaking post-graduate studies and hydrocarbon exploration.

David Maddocks, BSc Hons (Open), BA (Open)

Fire in the Sky: Comets and Meteors, the Decisive Centuries, in British Art and Science by Roberta J M Olson and Jay M Pasachoff, 1999, Cambridge University Press, 369pp, £18.95 (paperback) ISBN 0521663598.

This book gives an interesting insight into the history of comet and meteor sightings throughout the centuries.

The authors start by looking at the significant scientific developments and the tradition of comet and meteor representations during the seventeenth century. Discussion on the major players in the eighteenth century follows – their contributions to both art and science are outlined and collaborated by the use of some delightfully reproduced illustrations.

The nineteenth century saw a large number of comet sightings and, with a growing interest of the general public in things scientific, there was a greater public awareness of the phenomena. The use of comets and comet imagery in publications, drawings and poetry is examined.

During this century astronomical discoveries led to a more down-to-earth attitude and improved technology aided astronomers to investigate faint as well as bright comets. However, romantic attitudes were still in evidence and the authors examine these as well as recording the more pragmatic views.

A chapter in the book is devoted to the development of astronomical photography with suitable plates being illustrated. Some of the photographic plates taken in the mid-eighteen hundreds are reproduced.

The epilogue by Colin Pillinger outlines the more recent and future contributions of British scientists to cometary science.

I found this a fascinating book that inter-weaves the contributions of science and art to the recording of comets and meteors. It is full of carefully selected illustrations that provide a fascinating insight into the attitudes and beliefs held by people about these phenomena since the seventeenth century.

Jean Sampson BSc Hons (Open)

Granite: What? Where? Why? How? When?

Dr Pádhraig Kennan, Geology Department, University College Dublin.

Introduction

The term granite stretches a bit. The textbooks describe the rock as a granular, coarse-grained aggregate of quartz, various feldspars and micas and, in some varieties, hornblende. The mineral proportions differ from place to place. The textbooks also say that the coarse texture reflects slow crystallisation from molten magma at relatively shallow crustal depths, that a source at some depth must melt to produce the magma and that crystallisation follows upward intrusion into colder surroundings. If only that were all. The fact is that the understanding of the origin and intrusion of granite remains a matter for ongoing debate. This is so even in the light of worldwide field observation, ever more precise laboratory measurements of rock and mineral chemistry, ever more sophisticated high-pressure and high-temperature experiments - and periodic outbreaks of certainty.

Questions

For granite intrusion after granite intrusion, the same questions recur. Was the magma source some older granite? Was it some other rock type that partially melted to give a granite magma that, on departing upward, left a solid residue behind? Was what intruded entirely molten, did it entrain crystals or did it carry residual source material with it? Does the outcropping granite represent a fractionated derivative melt – a magma that lost early-formed crystals to the force of gravity? Even for those few overlapping questions, satisfactory answers are not easily found. The reason is simple. Only the rocks have ever seen a granite magma form, intrude and crystallise.

Inevitably, there are further questions for the rocks to answer. Did the intruding magma react chemically with the crustal rocks through which it passed? Did the molten granite perchance mix with other molten rocks at or above its source? Many outcrops show clear indications that these processes can and do happen. Even the commonplace xenolith encourages questions. How long might a xenolith remain as a discrete entity once it is ripped from solid wall rock and drawn into hot mobile magma? Partially assimilated xenoliths give notice that wholly assimilated xenoliths are, by definition, lost. With every one that is lost, granite mineralogy and chemistry is changed - and the question of source becomes less singular. What is the defining outcrop observation that will discriminate between granite into which micaceous wall rock has been assimilated and granite that originated in a heterogeneous source with micaceous components? There is a worst-case scenario. What if source heterogeneity, magma mixing, wall-rock assimilation and fractionation, just four of many possible conspirators, work together - as they frequently do? Untangling the end result is the trick. Finding the means is another.

Common or garden water can contribute to the confusion. When encountered at shallow crustal levels, it may halt granite intrusion and, by influencing the sequencing of mineral growth, may promote this or that granite texture. None of that would necessarily change the granite chemistry. However, the water that circulates around newly intruded granites is typically very reactive and loaded with just about everything that can be dissolved and transported in what is usually a salty solution. This hydrothermal water will certainly alter the chemistry of any granite into which it soaks. It is the rare granite thin-section that does not provide evidence of the hydrothermal alteration of feldspars and micas - a process that, in the extreme, may reduce hard granite rock to pottery clay. Some of the potential chemical changes are very obvious. The metals scavenged from granite wall rocks, for example, may reappear as enriched deposits hosted in altered and greisened marginal granite. Some subtle changes, on the other hand, might be recognised only after the precise measurement of oxygen isotope proportions.

How is any characteristic of an original molten granite to be definitively recognized through this plethora of overprinting processes? How are the rock samples that represent the start of a chain of forensic evidence to be selected? These samples must, somehow, characterise huge volumes of rock. They must also, somehow, enable recognition of what was original and the unmasking of what is secondary. Weathered samples have played many villainous bit parts in granite research.

The problems of granite do not end with compositional complexities. It may be a surprise but, in the case of many granite intrusions, even their volume remains in question. Though countless granite masses are accurately shown on geological maps, for many the perceived third dimension at depth is often no more than a tentative or modelled estimate. It does not help that field exposures are usually of limited vertical relief and that it is the near-roof parts of granite intrusions that tend to outcrop. Very few appear to have been tectonically tilted onto their sides. It does not help, either, that every gravity model is essentially just one of many possibilities and that seismic measurements still find difficulty in resolving the lower boundaries of intrusions. Without clear shapes and volumes, should it be any surprise that, except for the rare case, modes of intrusion remain unsettled and matters for lively discussion?

Buoyancy, aided and abetted by tectonic forces, reasonably explains the ascent of low-density granite magma from a melting source at depth. Exactly how this happened in any particular instance, however, is often a difficult question. Some intrusions may have been low-density diapirs that rose through higher-density crust and expanded like hot air balloons. Others appear to have invaded openings conveniently provided by contemporaneous shear zones. Sheeted intrusions, more and more of which have been recognised in recent years, may have been routed along pre-existing structural features such as bedding or cleavage. Domed, mushroom-like granite masses at shallow levels may have involved magma that spread out laterally after having journeyed rapidly up deeply-penetrating fractures.

Some of these options, of course, ask further questions. At what velocity might viscous granite magma flow at depth? Would a rising diapir, losing heat to its surroundings, manage to keep going for any great distance? What role might envelope rocks rich in fluxes, e.g. boron, fluorine and lithium, play during diapirism? How far has any particular granite travelled through the crust or, perhaps more interestingly, how far has it travelled relative to the rocks now surrounding it on outcrop? With outcropping granite,

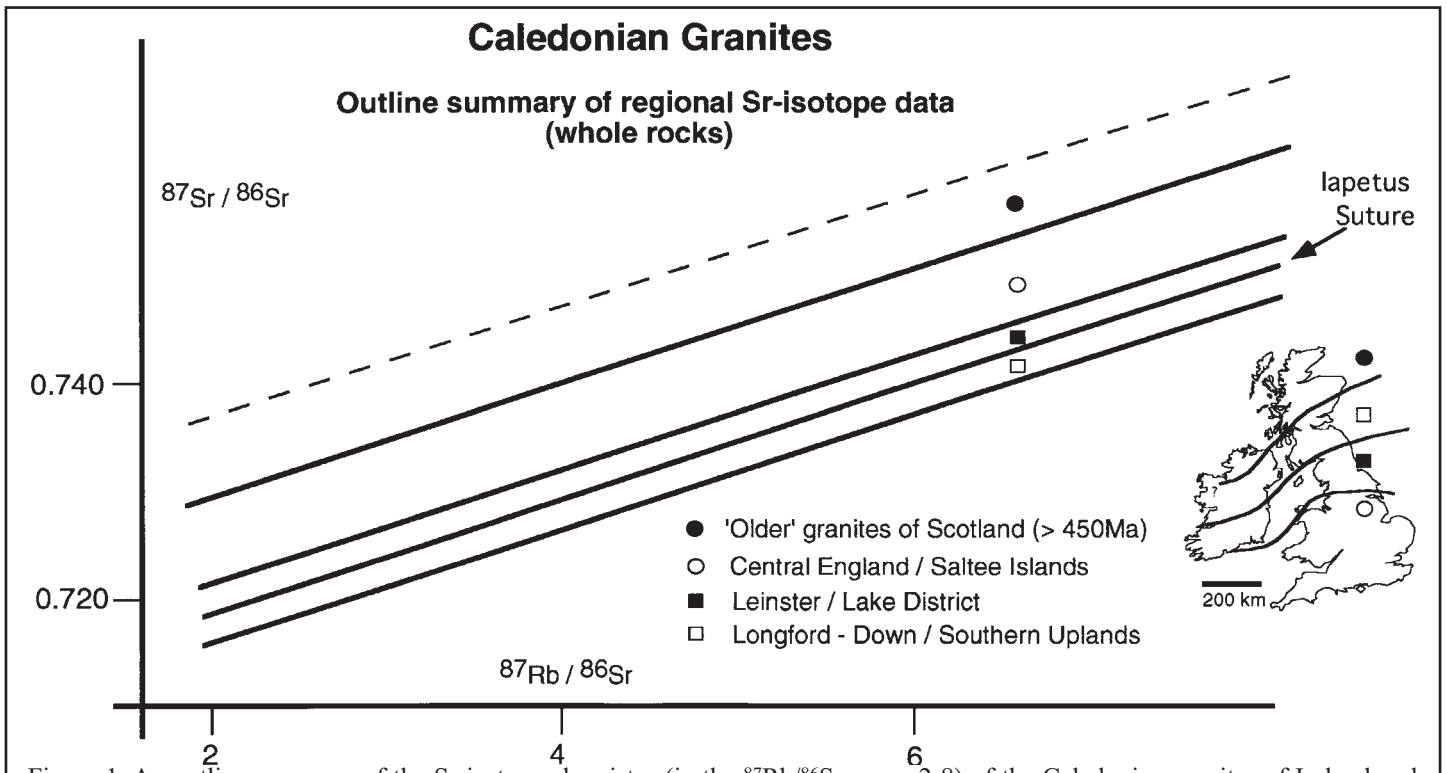

Figure 1. An outline summary of the Sr-isotope chemistry (in the $^{87}Rb/^{86}Sr$ range 2-8) of the Caledonian granites of Ireland and Britain. The data that were used to define the geographic domains come from numerous published and other sources. Making no assumptions linking individual data points to one another in any way, all of the data were simply plotted on the normal Rb-Sr isochron plot. Though the lines on the plot that separate data from the different domains have slopes that suggest 400Ma ages, these lines were in fact drawn so as to relate to major structural breaks such as the Iapetus Suture.

the questions always relate to events of long ago. The outcropping rock was the only witness. The experiment is hearsay - always one step, at best, away.

Intruding granites require space. After years of discussion about the room problem, there are still gaps between apparent need and hard field data. A deficit tends to appear wherever the accommodation made available is estimated by direct measurement of accommodating structures in the granite envelope. Some granite intrusions appear to take more room than they are given. Intrusion as sheets may reduce this apparent problem. Calling on remote adjustments prompts thoughts of dust and carpets - and there is probably another granite out there anyway.

The questions cascade on. Without an accurate knowledge of volumes, how is the energy required for melting to be even vaguely estimated - or the energy lost by a crystallising granite? How long, for instance, might a cooling granite continue to drive a hydrothermal system? Relatively young ore deposits immediately above some relatively old intrusions suggest that a hydrothermal activity may remain active for a very long time. The energy released on crystallisation that is, of course, responsible for the development of thermal aureoles was gained at the time of magma generation. However, the source of the energy required to melt whatever it was wherever it was remains a crucial question. The answers are usually speculative. The energy source may have resided in hot mantle material coming into contact, in one way or another, with lower crustal rocks. Alternatively, radioactive elements concentrated in the crust may have supplied the necessary energy, especially where, for one geological reason or another, heat loss to the surface was inhibited. It probably always is a matter of both.

There are so many questions with debate-laden answers. Many of the questions have been around for a long time. Perhaps the always complex and specific detail of the individual granite intrusion – the Papoose Flat or the Ardara or one's own favourite – exerts too great an influence. Perhaps the precise result from the precise experiment is a fatal attraction. Perhaps experiments and analyses have tended to involve materials too simple or too small-scale in one way or another to be, as yet, truly representative of real granite. As with the wood and the trees, might a useful alternative focus be the wider perspective provided by measured parameters that encompass hosts of more or less coeval, geologically-related intrusions, e.g. the Caledonian granites of Ireland and Britain? The whole-rock strontium-isotope data from this classic suite is one such all-embracing feature that this author finds interesting.

One view

Whole-rock strontium-isotope data are available for many individual samples from many Caledonian intrusions. These data have been, and are, a matter for question, doubt and relegation – especially in the context of age dating. However, these same data, simply collected and plotted as unprocessed raw data and without making any assumptions, reveal a number of coherent patterns. The abutting regional domains summarized on Figure 1 make one such pattern. In what is a large collection of data, few individual measurements plot outside their appropriate map domain. No gaps are apparent between domains. Only the Scottish granites are the exception; the Older Granites are clearly distinct whereas the Newer Granites are much more like the very different granites of the Southern Uplands. The Iapetus suture is clearly marked by differences between the granites north and south. In the context of the Iapetus Ocean, the apparent

continuity across strike that links all the data is interesting and, perhaps, surprising. Buried within the overall regional pattern are data from granites with ages that apparently span some 200 million years. Confined within the individual domains are subsidiary patterns – and more questions. Overall, however, the simplicity makes this large-scale view look promising.

What does the regional pattern mean? The ^{87}Sr (strontium) isotope originates by decay of the ^{87}Rb (rubidium) isotope. Thus, time is involved in Figure 1. Rb and Sr shadow potassium and calcium - key elements in the granite characterising minerals, feldspar and mica. Thus, granite chemistry is represented after a fashion on Figure 1. Finally, sources of differing Rb and Sr compositions, and sources of different ages, are potentially fingerprinted by differing ^{87}Sr compositions. Old, Rb-rich, crustal sources, for example, should result in ^{87}Sr-rich granites contrasting with those from young, Rb-poor, mantle sources. Thus, source difference is reflected on Figure 1. Time, the compositions of individual samples, and source chemistry conspire to provide a simple regional framework. Why?

For these granites on this regional scale, it does not seem to matter whether any or all of those processes that might have altered the chemistry of any of them occurred or not nor how complex their crystallisation histories might have been. All of the individual samples seem untroubled. With rare exception, each takes its place in a regional pattern that appears to reflect a coherent if varying regional source. That source lies on both sides of the Iapetus Suture. Could I hear that question again? How far did these granites travel?

The trees (granite samples) of this particular wood were not planted in a haphazard manner. Individual species occupy separate, strictly bounded adjacent plots. The overall formal layout reveals no differences in planting times. And there are many paths that lead to nowhere particular.

The questions cascade again. Is there a grail of any sort somewhere out there? Or a herring in murky waters? Is that H H Read hammering away in the far distance?

Book reviews

Fossil Plants and Spores: modern techniques by T P Jones and N P Rowe (eds), 1999, The Geological Society, 396pp, £29 (paperback) ISBN 186239041X.

This volume represents a recipe book of methods and approaches aimed at fossil plant material. The volume provides a comprehensive collection of techniques required for the successful study of fossil plants, spores and pollen. The volume includes traditional techniques developed over the decades together with the very latest ideas and methods particularly in the fields of biogeochemical analysis and palaeoclimatology. The volume is divided into ten sections with chapters written by an international array of specialists. The layout of the chapters follows a logical sequence of locating, collecting, extracting, analysing and preserving plant fossils and palynomorphs.

The majority of Parts One and Two deals with the extraction of plant macrofossils and palynomorphs from their sediments and their preparation and observation using photography, light microscopy and scanning electron microscopy. Part Three deals with the internal structure of plants and spores and includes a wide range of sectioning and embedding techniques including the familiar acetate peel technique. Part Four deals mainly with the preparation of material for transmission electron microscopy. Part Five deals with possibly the most rapidly developing field in fossil plant research – geochemical and biogeochemical analyses. Many of the techniques in this section require specialist equipment and dedicated operators. Part Six deals with the problem of naming plant fossils and their curation. The remaining sections deal with a diverse range of subjects such as sedimentology, stratigraphy, palaeoclimatology and palaeoecology demonstrating the importance of plants in stratigraphy and reconstructing ancient climates. A comprehensive bibliography, glossary and list of equipment suppliers are provided.

The volume is essential reading for palaeobotanists, palynologists, palaeontologists and academics teaching postgraduate and undergraduate levels in earth science university departments. Whilst many of the techniques in the book have been specifically designed for fossil plants, they can be adapted for other fossil groups. I see it being used mainly as a laboratory manual when specific techniques for plant study are needed rather than being read from cover to cover. This is certainly a major contribution and state of the art appraisal of plant and palynological techniques. Is there anything in this volume for the casual reader or those with a general interest in fossils? The plant fossil enthusiast can get a flavour of what can be discovered about the fossil plant record by dipping into the volume and reading any of the excellent self-contained contributions. A library copy is certainly worth a browse and a must for any serious student of fossil plants and palynomorphs.

Dr Alan Seago PhD, BSc Hons Geology, OU Tutor

Fluvial Sedimentology VI by N D Smith & J Rogers (eds), 1999, Special Publication Number 28 of the International Association of Sedimentologists, Blackwell, 478pp, £55.00, (paperback) ISBN 0632053542.

This volume contains 31 papers from the Sixth International Conference on Fluvial Sedimentology held in Cape Town in 1997, so it covers a wide range of up to date material on fluvial topics from around the world. It is divided into five sections by broad topic: Sediment Transport and Bedforms; Modern Fluvial Environments; Avulsion: Modern and Ancient; Controls on River Systems and Alluvial Successions; and Alluvial Facies and Architecture.

As this is a collection of conference papers, there is some complex material here, but it's good stuff! Though there is material about older deposits, the coverage is primarily on modern sedimentary environments. There are papers on new techniques for interpreting them, such as LANDSAT imaging of the 1997 Czech Republic flood, ground penetrating radar surveys of modern deposits in Australia, and the use of models in looking at alluvial architecture; as well as papers analysing the behaviour of sediments in these modern environments.

Three papers caught my eye: one on 'The geochemical and mineralogical record of the impact of historical mining within estuarine sediments from the upper reaches of the Fal Estuary, Cornwall, UK' by S. H. Hughes, based on PhD work. This describes the historical record of pollution to be found in these sediments and where and in what quantities they occur. Secondly, there is a paper on 'Controls on the sedimentology of the November 1996 jökulhlaup deposits, Skeiðarársandur, Iceland' by Russell and Knudsen, which describes the flooding caused by the melting of ice due to volcanic eruption. As we had visited the area not too long before these floods, this was interesting! Finally, 'Recognizing avulsion deposits in the ancient stratigraphical record' by Kraus and Wells - with all of the flooding last year we had been discussing how these events might be preserved in the record, and how a very short event like these could be recognised in older sediments - this paper looks at events in Wyoming in the Palaeogene, where there are sequences of sand lenses and paleosols.

However, this is only a selection of what is in this volume! As I say, it's advanced, but if anyone is going on to study fluvial sedimentology, it's well worth a look.

Jenny Bennett OU tutor, BA Hons (Open)

Caledonian Granites - Emplacement

Dr R John Reavy, Department of Geology, National University of Ireland, Cork, Ireland

Abstract

The Caledonian granites of Britain and Ireland were generated and emplaced after final collisional closure of the Iapetus Ocean in the late Silurian. Assessment of the controls on ascent and emplacement of granitoid magmas reveal that tectonic structures within this thickened crust were of crucial and dominant importance as ascent conduits. These conduits facilitated channelling of granitic melt from multifarious source regions to higher level emplacement where pluton construction took place between 420 and 400Ma. To obtain an overview, data from adjacent areas in Scotland must also be considered. The dataset currently available reveal that the Leinster granite was emplaced as a series of easterly dipping sheets of mixed magma batches of dominantly metasedimentary derivation within an extensional reactivated suture zone. Most of the other Caledonian granites were derived from crust with a substantial mantle involvement. The Galway granite is apparently sited along a major crustal structure associated with, but not entirely coincident with, the Skird Rocks Fault; emplacement then occurred by a process of ballooning or lateral spreading to the north and south above this zone. The Newry complex was constructed along reactivated bounding structures within the Longford-Down Massif. The controls on the Ox Mountains and Donegal complexes were NE-SW trending Caledonian structures associated with Caledonian transpressional collision or the interactions of these structures with reactivated Pre-Caledonian basement structures as has been clearly demonstrated in adjacent parts of SW Argyllshire. Emplacement related fabrics from granites in the British and Irish sectors of the Caledonian orogen give an overview of the state of strain of the orogen at this crucial time in its development.

Introduction

On a map of Ireland the occurrences of the main Caledonian Granite bodies may appear at first glance to be completely random (Figure 1). However, it is now clear that this distribution is far from random and that granite intrusions are intimately and totally controlled by deep crustal structures such as lineaments, shear zones and fault zones. These structures exert a fundamental control over all aspects of the magmatism, including the site of melting, the channelling of melts upwards and the consolidation of such melts to form bodies commonly known as plutons and batholiths. Over the years several misconceptions concerning granites have arisen and, before any examination of the individual complexes within Ireland, these need to be addressed.

Figure 1. Irish Caledonian Granites

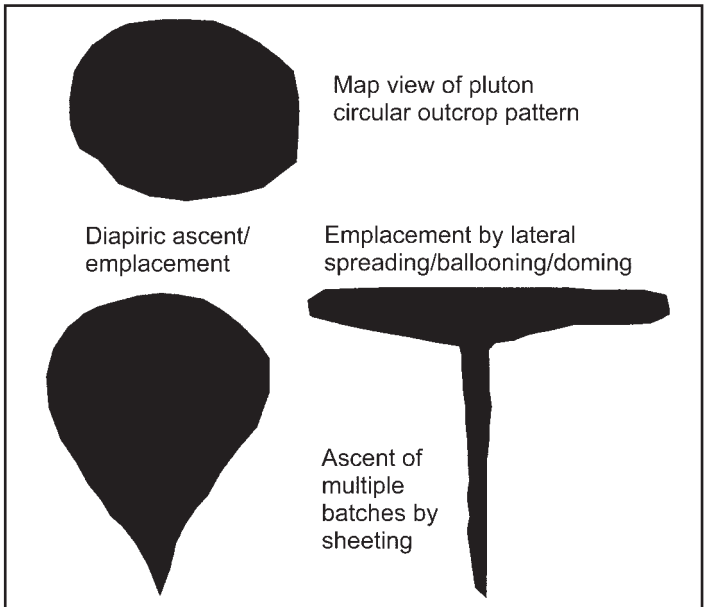

Figure 2. Cartoons relating to ideas of ascent and emplacement.

Misconceptions concerning granites

The first of these is the commonly seen cross-section of plutons and batholiths. Circular outcrop patterns on maps (Figure 2) are often drawn with steep outward dipping contacts in which the granite exposed at the surface is merely the tip of a huge volume of igneous rock which is depicted continuing downwards to unimaginable depths in ever increasing volumes. It is now generally accepted that most granite bodies are actually flattish or gently inclined tabular or sheet-like in form, often only several km thick.

The second area of confusion arises from the perceived intrusion mechanism. For too long granites have been envisaged as large spherical blobs of magma (Figure 2) rising mysteriously as some semi-consolidated mass shouldering the surrounding rocks apart and somehow managing to traverse perhaps 15 or 20km vertically through the crust before eventually coming to rest. These ideas were embodied in the concept of diapirism which is now largely discounted as being thermally and mechanically unfeasible.

Ascent and Emplacement of Granites

It is more useful to distinguish two distinct processes: ascent and emplacement (Figure 2).

Ascent is the vertical movement of melt from source region to somewhere higher in the crust where emplacement occurs. Ascent

will be facilitated by the presence of tectonic structures within the crust such as shear zones and fault systems and is most likely to occur by a process of dyke-like sheeting. Large amounts of magma can therefore be channelled up such a conduit although the overall zone of magma transport is not unfeasibly large. It is envisaged that magma will ascend as a series of multiple batches rather than one large homogeneous mass.

Emplacement is the process of construction of plutons at the arrival level from the multiple batches which have arrived at a certain level in the crust. The dominant processes operating here will be lateral spreading/sill construction or *in situ* ballooning in which magma pressure will uplift or updome the adjacent rocks.

A circular outcrop pattern on a geological map (Figure 2) should therefore not be taken to represent the top of a large steep sided body and it is most likely that it is a flattish disc-shaped body which was fed by a narrow vertical conduit. Linear granite bodies on close examination are usually found to be composed of vertical sheets which may still have been in ascent when crystallization occurred. The volume problems which have long dominated research on granites have now been greatly reduced.

Fabric development during crystallization

Methodologies are now well established which allow the assessment of the temperature and timing of deformation throughout the crystallization interval and emplacement related kinematics to be determined. Central to such ideas is the concept of a defining rheological critical melt percentage (RCMP) at which the viscosity dramatically increases. At its simplest, this allows fabrics seen in granites to be assigned as either pre-RCMP (magmatic state) or post-RCMP (solid state), (see Tribe & D'Lemos 1996 for a full review).

Caledonian Granites - Setting

The Caledonian granites in Ireland (Figure 1) were emplaced towards the end of the Caledonian orogen between 420-400Ma at the end Silurian/early Devonian. To understand their emplacement, a brief review of the previous geological history of the lithosphere into which they were emplaced is necessary. The granites were emplaced into a lithosphere thickened as a result of the final collisional closure of the Iapetus Ocean towards the end of the Silurian. Many NE-SW trending faults and shear zones associated with this collision were active at this time and were utilized by ascending magmas. However, other pre-Caledonian structures within both the orogen and its basement were reactivated and magmatism was focussed where these two sets of crustal structures interacted.

Caledonian Granites – Details

The largest body of granite in Ireland is the Leinster batholith (Figure 3) which outcrops over an area of 1500km^2. In contrast to the other Caledonian granites it is largely derived from anatexis of a metasedimentary source and is largely, but not exclusively, composed of peraluminous two-mica granite. The batholith is emplaced into the Lower Palaeozoic Leinster massif which is a sequence of oceanic metasediments and metavolcanics, which represent the NW Irish Avalonian margin.

It has long been recognised that the massif has a very complex and heterogeneous deformation history which predates granite generation and emplacement (Brindley 1956, 1973; Brück 1968; Shannon 1979; McArdle & Kennedy 1985; McArdle *et al*. 1987).

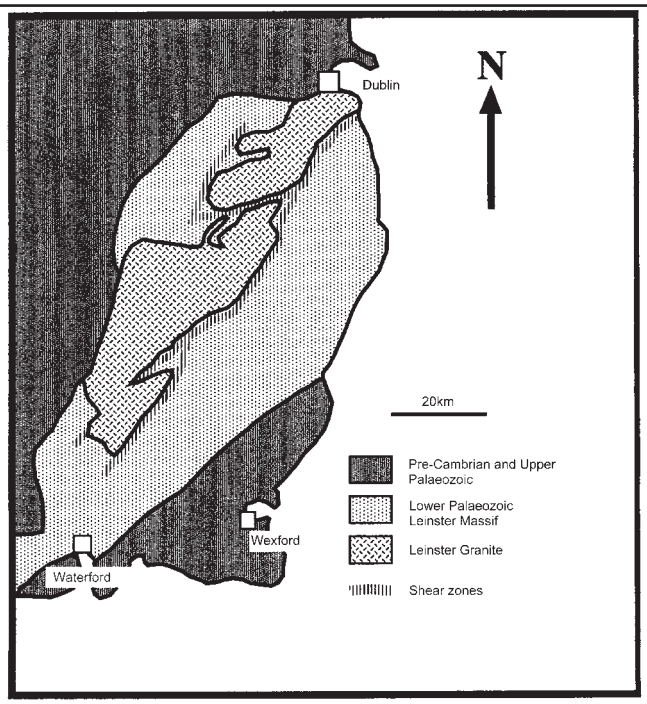

Figure 3. The Leinster batholith, SE Ireland.

Several authors have proposed emplacement models for the granite. Brindley (1973) realised that the batholith was composed of flattish sheets and favoured emplacement into a dextral rotational stress system similar to a tension gash array. Other workers (Cooper & Brück 1983; McArdle & Kennedy 1985) realised that the relationship between emplacement kinematics and regional tectonic deformation was complex and equivocal in certain areas. Recent work (O'Mahony & Reavy in prep.) has emphasised the existence of a major shear zone structure which can be traced along strike within the massif from Dublin towards Waterford. This probably represents a reactivated collisional suture zone which acted as the major siting structure for the magmatism. Detailed work now favours a model in which emplacement of gently inclined tabular granite bodies was facilitated by transtensional reactivation of this and other linked and anastomosing shear zones within the massif. The overall setting of the batholith is proposed as a transtensional jog within an overall transpressive tectonic regime. Detailed mineralogical and textural evidence (Grogan & Reavy in prep.) show that complex mixing processes were operating as batches of magma were generated within the extensional system.

The Galway batholith (Figure 4) was emplaced into the Connemara Gabbro and Gneiss Complex which represents a deformed arc complex which collided with the Laurentian margin during the 470-460Ma Grampian event (Friedrich *et al*. 1999). The Skird Rocks Fault is considered by Leake (1978) to be a splay of the Southern Uplands Fault and to have strongly influenced the siting of the batholith. However, gravity and aeromagnetic studies have shown that the granite extends south under Galway Bay and the northern Burren (Murphy 1952; Max *et al*. 1983; Madden 1987) giving overall dimensions of 90km by 35km with the long axis oriented WNW–ESE, oblique to the Skird Rocks Fault. Although this structure may have been involved in siting the complex, a model where this is the sole control is clearly not feasible.

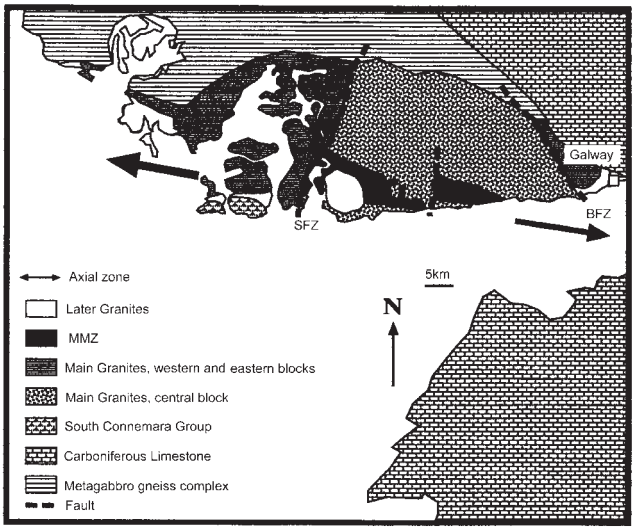

Figure 4. The Galway batholith, western Ireland.

The batholith is composed of western, central and eastern blocks separated by the Shannawona and Barna Faults. Gravity studies by Madden (1987) show that the central block is 3-4km thinner than the western block, implying uplift of the central block along the Shannawona Fault; it is thought therefore that the central block represents a deeper erosion level. The bulk of the complex comprises a spectrum of lithologies ranging from diorite through granodiorite to granite. Of critical importance is the unequivocal evidence of a steep linear axial zone of magma sheeting, mixing and mingling (MMZ) in which complex mafic/felsic magma interaction has taken place. This zone represents a deep seated transbatholithic shear zone which has acted as an ascent site for much of the early magmas which clearly show abundant evidence of mantle/crust interaction. El Desouky *et al*. (1996) have presented an elegant model linking mingling phenomena within this zone with erosion level displayed, again emphasising the role of steep faults in explaining the facies distribution mapped.

If the complex extends south of Galway Bay under N. Clare, this early part of the batholith can be envisaged as being broadly elliptical in shape, comprised largely of "I-type" lithologies in a spectrum from diorite through granodiorite to granite and with a major deep-seated axial ascent zone of mixing and sheeting. Detailed fabric analysis (Feely *et al*. in prep.) have shown that flattening fabrics are intense along the northern contact and along the axial ascent zone. A model involving ascent followed by lateral spreading and ballooning outwards from this zone to the north and south is being proposed.

The Donegal batholith (Figure 5) is one of the most famous granite complexes in the world, principally due to the lifetime work in the area led by Professor W S Pitcher. His book on the Geology of Donegal is one of the most important works in the granite literature (Pitcher & Berger 1972). The Donegal granites along with those in the Grampian Highlands of Scotland were emplaced into the Laurentian margin. Recent models (see Jacques & Reavy 1994; Hutton & Alsop 1996 for more details) have shown that the construction of the plutons in this region are intimately controlled by the intersections of crustal structures within the Proterozoic basement and the Caledonian cover. In Donegal, many of the granites (Thorr, Trawenagh Bay, Rosses) lie along the N12E-trending Donegal lineament which is a major long lived structure

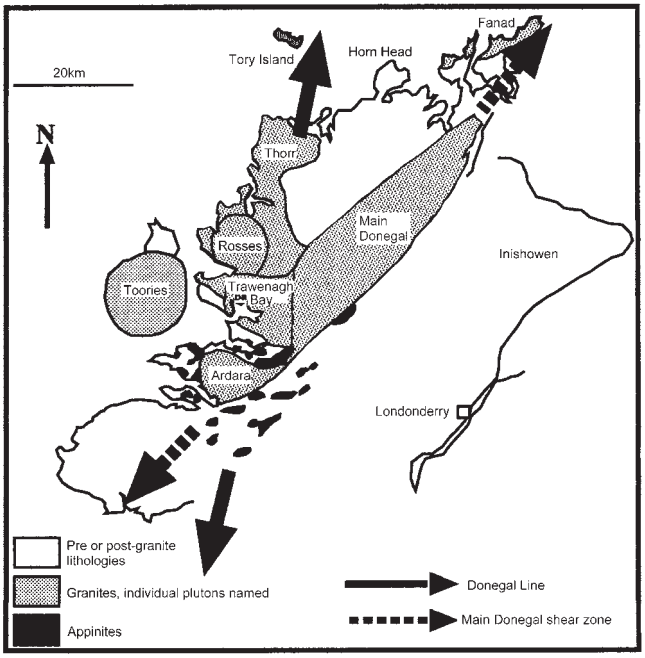

Figure 5. The Donegal batholith and Appinite suite, NW Ireland after restoration of the Leannan Fault. (Modified from Hutton & Alsop (1996), fig 13, p354).

active as far back as continental rifting and deposition of the Dalradian sedimentary succession. The Main Donegal granite is a classic example of pluton construction by a process of vertical sheeting within an active Caledonian NE-SW-trending shear zone. The Ardara body is an excellent example of a circular body sited at the intersection of these two structures. The abundance of the mantle-derived appinite suite concentrated in the Ardara area is evidence of the deep channelling of magmas along lithospheric structures in this area.

The Ox Mountains complex is another sheeted complex emplaced within a major NE-SW sinistral shear zone associated with the Fair Head-Clew Bay fault zone, the continuation of the Highland Boundary Fault in Ireland. A comprehensive model has been presented by McCaffrey (1992).

The Newry complex is located within the Longford-Down massif, the continuation of the Southern Uplands in southern Scotland. It consists of three plutons, again aligned NE-SW along the Caledonian strike. Work in progress (Hurley & Reavy in prep.) has shown that space for emplacement of the magmas was created by reactivation of tract bounding structures within the sedimentary sequence. However, there is also evidence emerging of deeper NW-SE-trending structures controlling siting of basic magmas at the NE end, (a similar intersection to what is seen at Ardara) and at the SW end where the Tertiary Slieve Gullion complex is also located.

Conclusions

It is now apparent that crustal structures were the dominant control in siting, ascent and emplacement of the magmas which form the Irish Caledonian granites. In several situations reactivation of pre-Caledonian structures in the basement or the cover played a critical role along with Caledonian shear zones which were operating during the final transpressional Iapetus closure. The distribution of the granite bodies on the map is therefore far from ran-

dom; indeed, careful study of the emplacement mechanisms involved can provide valuable information about the overall tectonic development and state of strain of the orogen itself.

References

Brindley J C, 1956, The geology of the northern end of the Leinster granite: Part II, Structural features of the country rocks. *Proceedings of the Royal Irish Academy*, **58B**, 23-68.

Brindley J C, 1973, The structural setting of the Leinster Granite - a review. *Scientific Proceedings of the Royal Dublin Society*, **5**, 26-33.

Brück P M, 1968, The Geology of the Leinster Granite in the Enniskerry-Lough Dan Area, Co. Wicklow. *Proceedings of the Royal Irish Academy*, **66**, 53-70.

Cooper M A & Brück P M, 1983, Tectonic relationships of the Leinster granite, Ireland. *Geological Journal*, **18**, 351-360.

El Desouky M, Feely M & Mohr P, 1996, Diorite-granite magma mingling and mixing along the axis of the Galway Granite batholith, Ireland. *Journal of the Geological Society*, London, **153**, 361-74.

Friedrich A M, Bowring S A, Martin M W & Hodges K P, 1999, Short-lived continental magmatic arc at Connemara, western Irish Caledonides: Implications for the age of the Grampian orogeny. *Geology*, **27**, 27-30.

Hutton D H W & Alsop G I, 1996, The Caledonian strike swing and associated lineaments in NW Ireland and adjacent areas: sedimentation, deformation and igneous intrusion patterns. *Journal of the Geological Society, London*, **153**, 345-360.

Jacques J M & R J Reavy, 1994, Caledonian plutonism and major lineaments in the SW Scottish Highlands. *Journal of the Geological Society, London*, **151**, 995-969.

Leake B E, 1978, Granite emplacement: the granites of Ireland and their origin. In: Bowes D R & Leake BE (eds) *Crustal Evolution in Northwest Britain and Adjacent Regions*, pp. 221-48. *Geological Journal, Special Issue,* **10**.

Max M D, Ryan P D & Inamdar D D, 1983, A magnetic deep structural geology interpretation of Ireland. *Tectonics*, **2(5)**, 431-51.

Madden J S, 1987, *Gamma-ray Spectrometric Studies of the Main Galway Granite, Connemara, West of Ireland.* Ph.D. Thesis, National University of Ireland.

McArdle P & Kennedy M J, 1985, The East Carlow Deformation Zone and its regional implications. *Geological Survey of Ireland Bulletin*, **3**, 237-255.

McArdle P, Gardiner P R R, Feely M, & Colthurst J R J, 1987, A possible western extension of the East Carlow Deformation Zone: A preliminary note. *Geological Survey of Ireland Bulletin*, **4**, 63-66.

McCaffrey K J W, 1992, Igneous emplacement in a transpressive shear zone: Ox Mountains Igneous Complex. *Journal of the Geological Society, London,* **149**, 221-235.

Murphy T, 1952, *Measurements of gravity in Ireland, Gravity Survey of central Ireland*, D.I.A.S. Geophysical Memoirs **2**, part 3, 31pp.

Pitcher W S & Berger A R, 1972, *The Geology of Donegal: a Study of Granite Emplacement and Unroofing.* Wiley Interscience.

Shannon P M, 1979, The tectonic evolution of the Lower Palaeozoic rocks of extreme SE Ireland. In: Harris A L, Holland C H and Leake B E (eds.) *The Caledonides of the British Isles - Reviewed.* Geological Society of London. Special Publication, **8**, 281-285.

Tribe I R & D'Lemos R, 1996, Significance of a hiatus in down-temperature fabric development within syn-tectonic quartz diorite complexes, Channel Islands, UK. *Journal of the Geological Society, London*, **153**, 127-138.

Book reviews

Gold by Richard Herrington, Chris Stanley and Robert Symes, 1999, Natural History Museum, 64pp, £7.95, (paperback) ISBN 0565091417.
This book forms part of a series of books published by the Natural History Museum. The books are aimed at those with only a little scientific background or older children, but are not so simple that they are unsuitable for OU students. They are attractive with numerous colour photos and diagrams with simple, easy to read text. The books were written to accompany exhibitions at the Natural History Museum. The series is reasonably priced.

Only the first half of this little book is relevant to geology, covering mineralogy, where gold is found, how it accumulates, gold in metamorphic rocks, sediments, volcanic association, exploration, exploitation and extraction. The first 7 pages are an introduction covering properties of gold, its chemistry, an explanation of a carat and a list of unusual gold minerals.

There is a clear, useful diagram summarising the geological settings for gold. Some of the diagrams are quite complex, like the gold deposits in large fault or shear zones, the map of Barry Canyon and the geochemical map. These areas are covered fairly comprehensively.

The second half, pages 36 to 63, covers several topics with just a few paragraphs on each. It covers the history aspects - gold rushes, antiquity, ornaments, jewellery, medicinal use, goldsmithing, myths and fantasy, which I suppose means it should contain something to appeal to everyone. It looked to me to be very superficial but obviously the authors were very limited by the space available. I assume the exhibition determined the contents and it does seem more like a catalogue.

Wendy Hamilton, OU Tutor

Sedimentology and Stratigraphy by Gary Nichols, 1999, Blackwell Science Ltd., 328pp, £26.50 (paperback) ISBN 0632035781.
This 24 chapter book deals with nearly every aspect of sedimentary geology that you might need to cover, beginning with nomenclature and classification of clastic rocks, and finishing with dating techniques and lithostratigraphic correlation. On the way, the author discusses terrigenous, carbonate and volcanogenic sediments, sediment transport and structures, facies and environment, post-depositional processes, tectonic settings and eustatic sealevel change. He touches on many topics relating to igneous rocks, such as magnetic anomalies and various types of volcanism.

Each chapter begins with a quick summary, and the text is printed two columns to a page in short, easily digested sections with clear headings which can be taken in at a glance. Each chapter finishes with a list of books for further reading. A full bibliography is given at the end of the books, and there is a good index. The book is generously illustrated with clearly labelled figures and illustrations, positioned close to the relevant parts of the text.

Not being a fan of formulae or equations, I am glad to say there are very few in this book. Explanations of concepts are direct and lucid. Most of the book was revision for me, but the information is put over in a way that could easily be absorbed by readers new to geology. I felt that forgotten concepts were made clearer, and some terms were new to me - for instance, ichnofossils, ravinement, sequence stratigraphy and parasequences.

Altogether an enjoyable read. I would recommend Gary Nichols' book to anyone who intends to spend the rest of their life contemplating rocks, at whatever level. £26.50 is a reasonable price to pay for a concise and uncluttered companion to future studies.

Anne Morton, BSc Hons (Open)

The Valentia Island Devonian Tetrapod Trackway - First Tentative Steps

Dr Ken Higgs, Department of Geology, University College Cork, Ireland

Figure 1. The Valentia Island Devonian tetrapod trackway.

The Devonian tetrapod trackway on Valentia Island in southwest Co. Kerry is one of the most important palaeontological sites in Ireland, if not Europe (Figure 1). It was first discovered by a geology student, Ivan Stossel, in 1992. It has thrown new light on the first colonisation of land by vertebrate animals, and so is very important from an evolutionary point of view.

At the end of the Silurian Period the continents of Laurentia, Baltica and Avalonia eventually collided to form the supercontinent of Laurasia, commonly referred to as the 'Old Red Sandstone' continent. The southern margin of this continent lay close to the equator. This meant that parts of the continental interior were hot and arid. Most of the evidence for the first colonisation of land, whether it is by plants or vertebrate animals, has been obtained from fossil finds on the ORS continent.

Ireland and Britain would have been positioned on the southern margin of this continent during Devonian times, and we can imagine what the environment would have been like. Newly formed mountains were rising to the north as a result of the continental collision, providing huge amounts of sediment to this southern margin. The coastal zone consisted of low lying regions, supporting a few primitive plants. The late Silurian - early Devonian land plants had simple naked stems with no true leaves and would have been less than a metre in height. All of the vertebrate life at this time was in the water. It consisted of various groups of fish; in particular the ray-finned fish, where the small bones of the body support the fins, and the lobe-finned fish, which had fleshy fins with bones extending down into the fin itself. It is believed that it is from the lobe-finned fish that the first primitive amphibians evolved, based on many close anatomical similarities between the lobe-finned fish and the earliest tetrapods, ie. the overall shape, the structure of the skull, limb-bones and the teeth. In particular, it is thought that a specific group of lobe-finned fish, the Rhipidistrians, provided the ancestor of the first tetrapods. Ahlberg & Milner (1994) have suggested the Panderichthytids, a group of Rhipidistrians, are the most likely ancestors.

Once vertebrates began to colonise the land everything changed; this was indeed a momentous step in evolutionary history. The fossil skeletal evidence for this evolutionary step is restricted to

the Upper Devonian rocks; however, earlier fossil evidence comes from trace fossils. This is where the Valentia trackway provides important new information. The trackway is located on the northern coast of Valentia Island, which is situated in Co. Kerry, southwest Ireland. The Devonian rocks of this area were deposited in a large fault-bounded subsiding basin, known as the Munster Basin. At least 7000m of continental sediment accumulated in this basin, with the depocentre situated in the Kerry Mountains just south of Killarney. In the Valentia Island area there is an approximately 5000m thick succession of Old Red Sandstone exposed on the northern limb of the Portmagee anticline. Here the Old Red Sandstone succession is divided into three broad formations, with the tetrapod trackway occuring in the stratigraphically lowest formation, the Valentia Slate Formation. Other fossils found in this formation include fish described by Russell (1981), and plant spores described by Higgs in Williams *et al.* (2000). The fish and spore data indicate a late Givetian - early Frasnian age. Lithologically, the Valentia Slate Formation is characterised by purple siltstones and mudstones, with some purple and green sandstones. Sedimentologically, these rocks are interpreted as a fine grained alluvial facies, deposited on flood plains. End Carboniferous Variscan deformation has imparted an intense cleavage, and in the past these rocks were locally worked for high quality slate. Interestingly, within this thick red bed sequence there are extrusive and intrusive igneous rocks. Of particular importance are two silicic volcanic tuffs occurring above the tetrapod trackway horizon, the Keel Tuff (5m thick) located on the southern limb of the Portmagee anticline and its correlative, the Enagh tuff (11m thick) located on the northern limb of the anticline. These tuffs have a coarse crystal base, but on the whole are fine grained and of Plinian type. The geochronology of these tuffs has been established using radiometric dating of magmatic zircons, and in each case give ages of 385Ma (Williams *et al.* 2000). Using the recently published timescale of Tucker *et al.* (1998), this isotopic age correlates with a late Middle Devonian (Givetian) age. This ties in well with the spore biostratigraphy, which also indicates a late Givetian to earliest Frasnian age.

Ivan Stossel from the Geological Institute, ETH Zurich was carrying out his undergraduate mapping project, supervised by Dr. Mary Ford, when he discovered the trackway. There are 150 imprints preserved in a parallel meandering pattern. They are preserved as concave epi-reliefs, approximately 20mm in depth. Some imprints are infilled with sediment from the overlying layer. Unfortunately, there is very little detail of the digits and only one imprint shows a rough bilobate outline. Interestingly, there are two distinct sizes of imprint; a smaller set interpreted as manus forelimb impressions and a larger set interpreted as the backlimb pes impressions. These alternate systematically along the trackway. So there is a clear indication that there were two limb sizes. The details of the trackway were described in a paper by Stossel (1995) and in the analysis a number of parameters were measured, such as the pace, stride, pace angulation, and width of pace. These parameters were measured to find out something about the size and gait of the animal that produced the tracks. Unfortunately, the rocks have been tectonically deformed by the Variscan deformation. A strong tectonic cleavage runs perpendicular to the trackway, and this has caused a concertina effect in the rocks, tectonically shortening the original trackway. Using strain analysis techniques, a field of study that Zurich is famous

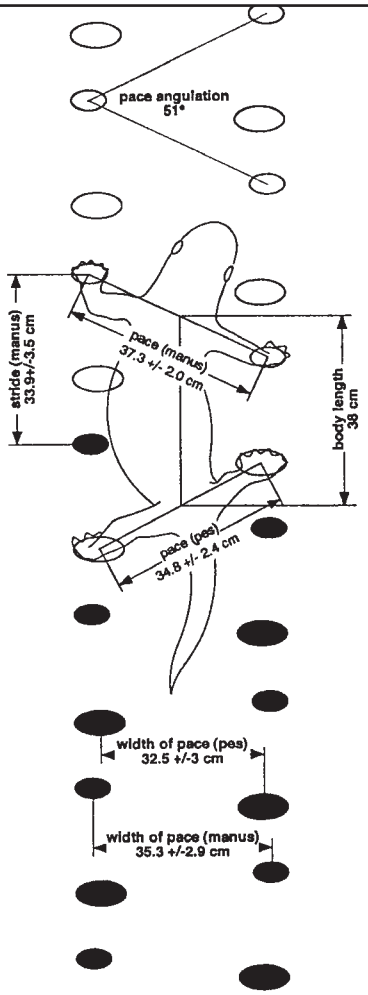

Figure 2. Estimations of body size computed from measurements taken from the trackway. (Modified from Stossel 1995)

for, Stossel was able to un-deform the rocks, and calculate a tectonic shortening of 47%, using the method of minimal quadratic deviation. Estimation of the body size, using the distance between the shoulder and hip, was calculated as 470mm. A total body length of about one metre was then deduced from ratios of known Devonian amphibian skeletons (Figure 2).

What did the animal that made these tracks look like? The popular press had their own ideas and announced that we had dinosaurs roaming Ireland during the Devonian (approx. 200Ma too soon) and a lot of publicity was attracted including a measure of political satire. Subsequently, a large number of radio and television interviews helped to put the story right and assign the tracks to a primitive amphibian.

However, trying to pin-point the actual animal that left this track is not easy. There is very little skeletal evidence of amphibians in the Devonian and all the known discoveries are from Upper Devonian rocks and all are much younger than the tetrapod trackway on Valentia Island. Interestingly, these skeletal remains show a variety in the number of digits (once we get into the Carboniferous there are always five). The best known examples are *Ichthyostega* and *Acanthostega* from Greenland. *Acanthostega* has been reinterpreted by Coates & Clack (1995), who now consider that this animal had a predominantly aquatic lifestyle, mainly living in plant-choked swampy waters, using its

limbs to manoeuvre and dig in the shallow water. However, other tetrapods such as *Hynerpeton* probably lived on land, based on the possession of strong shoulder bones indicating the animal could support its own weight.

What about the lifestyle of the Valentia tetrapod? The small pace angulation and the meandering nature of the trackway suggest the trackmaker was a sluggish mover. Sedimentological studies show that it walked on an alluvial flood plain which may have supported temporary ponds. However, it is unlikely that footprints would be preserved in a surface which was permanently water covered. The absence of tail drag is problematic but it may be that the animal had a short tail or possibly the upper layer of sediment containing the tail marks has been eroded away.

Previous Devonian records of tetrapod tracks are from the Upper Devonian of Australia and Brazil, both younger than the Valentia trackway. There is only one other trackway which is claimed to be older than the Valentia Trackway. This is in Victoria, Australia where Warren *et al.* (1986) describe a sandstone slab with 23 impressions in the courtyard of a building. However, the slab is not *in situ* and its original location has not been identified. This means that there is a question mark hanging over the provenance of the Australian example and, therefore, the oldest claim must be treated with caution. So, at present, the Valentia trackway is the oldest reliably dated and *in situ* tetrapod trackway in the world. The international importance of the site has been highlighted by an article in the *National Geographic* (Westenberg 1999) and more recently in an RTE television programme *Out Of the Blue*.

Conservation of the site is of major concern. In recent years large slabs containing important fossils from other sites in Ireland have been taken by professional fossil collectors. Unfortunately, there was no protection in law for these sites. However, the wide publicity relating to the Valentia trackway has caught the attention of the Minister for Heritage and action is now being taken to protect important geological sites in Ireland. The Geological Survey of Ireland, in particular Matthew Parkes, along with the geological community have drawn up a list of important paleontological sites that are to be protected in law. The Valentia trackway site was selected as the first geological site to be designated as a Natural Heritage Area and the Irish Heritage Board (Duchas) have purchased the site and so it is now protected in law.

Another threat to the site is natural erosion. The trackway is on the Atlantic coast and is constantly attacked by storm wave action. It is most likely that this site was not exposed in the 19th century as it was not recorded on the original maps and very detailed field slips of the Geological Survey of Ireland. However, anecdotal evidence suggests the surface containing the trackway was uncovered by erosion in the early part of the 20th century because the rock platform was known to some of the local people as 'Carrig na Ghur', which interpreted means 'rock of the hooves'. This evidence indicates the rapid speed of erosion taking place along the Valentia coastline. Perhaps a more long term policy will have to be adopted to save this important site. Some replica casts of the trackway have been made and reside in the heritage museum at Knightstown and in the Department of Geology, University College, Cork.

Finally, it remains for us to speculate on why this primitive tetrapod was tempted out of the water onto dry land. It could be that lakes and rivers temporarily dried up eventually forcing adaptation on to land, or that the early land plants provided a new food source. The most likely explanation is that it was very thirsty and was looking for some traditional Irish hospitality!

References

Ahlberg P E & Milner A R, 1994, The origin and early diversification of tetrapods. *Nature*, **358**, 507-514.

Coates M I & Clack J A, 1995, Romer's gap: tetrapod origins and terrestriality. *Bulletin du Muséum National d'Historie naturelle Paris, 4ème Série.* **17**, 373-388.

Russell K J, 1981, Vertebrate fossils from the Iveragh peninsula and the age of the Old Red Sandstone. *Irish Journal of Earth Sciences*, **1,** 151-162.

Stossel I, 1995, The discovery of the Devonian tetrapod trackway in SW Ireland. *Journal of the Geological Society of London*, **152**, 407-413.

Tucker R D, Bradley D C, Ver Straeten C A, Harris A G, Ebert J R & McCutheon S R, 1998, New U-Pb zircon ages and the duration and division Devonian time. *Earth and Planetary Science Letters,* **158**, 175-186.

Warren A A, Jupp R & Bolton B, 1986, Earliest tetrapod trackway. *Alcheringa*, **10**, 183-186.

Westenberg K, 1999, From fins to feet. *National Geographic*, **195 (5)**, 114-127.

Williams E A, Sergeev S A, Stossel I, Ford M & Higgs K T, 2000, *U-Pb zircon geochronology of silicic tuffs and chronostratigraphy of the earliest Old Red Sandstone in the Munster Basin, SW Ireland.*

Book review

The Oxford Companion to The Earth by Paul L Hancock & Brian J Skinner (eds), 2000, Oxford University Press, 1174 pages, £39.50 (hardback) ISBN 0198540396

This is a splendid book, full of concise and readable entries on phenomena, processes and natural materials relating to the Earth. It encompasses the atmosphere and oceans as well as the solid Earth and also other planetary bodies in our Solar System. The compilation of the book took several years and over 200 scientists contributed entries – including a few from the Department of Earth Sciences at the OU. With over 900 entries and 600 excellent illustrations this was indeed a mammoth undertaking and it is rather sad that Professor Paul Hancock, the original Editor-in-Chief, died before the task was completed. Entries are arranged alphabetically, beginning with 'acid rain' and ending with 'zoogeomorphology' but this book is much more than a dictionary or encyclopaedia and I soon found that it is essential to refer to the excellent index before trying to look up a particular topic. For example, the entry about dunes will not be found under 'D' but under 'A' – aeolian processes. To explore a particular subject area the reader can consult the six pages of thematic lists which bring together the headwords for entries in specific areas, for example Atmosphere, Geological time, Oceanography, etc. Entries vary in length from a paragraph or two to several pages. The Appendices cover Geological Timescales, facts about the Earth and Solar System, The Periodic Table, Scientific units, notation, conversion tables and abbreviations used in the Earth Sciences. Eight palaeogeographic maps appear as endpapers. I like the description in the Preface of a true companion as "... an object with which one feels comfortable ... to which one can turn for advice and counsel." This Companion deserves this definition and it should appeal to a wide readership. Browsing through it brings to light some unexpected entries, for example 'geological humour' and 'art and the Earth sciences'. There is a wealth of information here and at £39.50 it would be a book well worth buying.

Elizabeth Maddocks BA (Open)

Tidal Cycles in the Geological Past

Paul Dowdall, Department of Geology, University College Cork, Ireland

Abstract

The Moon is receding from the Earth at the rate of 3.8 cm/yr. Estimates of the Moon's past orbit and the length of day have been obtained from corals, bivalves, stromatolites and tidal rhythmites. This article gives a brief history of the study of the length of day from these sources and introduces a new concept in this area. Also, there is a quick look at an Irish tidally influenced deposit.

The Moon is receding from the Earth at the rate of 3.8 centimetres per year. The Earth's rotation is slowing, partially due to tidal friction. We can think of the Moon's recession and the slowing down of the Earth's rotation as a redistribution of angular momentum within the Earth-Moon system. As the Earth's rotation slows, the Earth-Moon distance must increase to conserve angular momentum within the system. Conversely, if the Moon were closer to the Earth, the Earth's rotation would be faster, and there would be shorter days with more days per year. So, the study of the Moon's orbit and the Earth's rotation in the past is generally known as the study of the length of day.

In palaeontology this means examining growth increments in corals, bivalves and stromatolites. In sedimentology the length of day has been inferred from comparing the thickness of sand/mud couplets in tidal rhythmites, and examining chert haematite structures in banded ironstone formations.

The study of coral banding (Scrutton 1978, Pannella 1975, Wells 1963) threw up some interesting issues about shorter days in the past. However, the problem with coral bands, or growth ridges, is that different observers have different ideas about what constitutes a growth ridge. This is because corals have no internal structures that correspond to the external growth ridges. This makes reliable estimates of the number of days per year, or the number of small daily growth ridges between large annual growth bands, almost impossible to verify. Values taken from counting coral ridges such as 400 days per year in the Carboniferous and 420 days per year in the Ordovician are still widespread in geological literature, but it is impossible to realistically interpret any cycle other than maybe a yearly banding cycle in ancient corals.

Bivalves show daily banding within annual banding (Evans 1972); this is because their internal structure records their incremental growth. They give estimates of the number of days per year at 383 in the Lower Carboniferous from 3 specimens and 405 in the Devonian from one specimen. As can be seen from the number of specimens used to make these estimates it is very difficult to find ancient bivalves that record the number of days in a year. In many bivalves growth does not occur all year round and the position of the bivalve within the tidally affected zone influences its growth pattern.

In stromatolites there clearly is banding (Jones 1981, Scrutton 1978, Pannella 1975, Mohr 1975, Vanyo 1985), but there is no agreement as to what causes this banding. Modern analogues of ancient stromatolites indicate that a storm or seasonal variation in algal growth is more likely than a fortnightly or daily one. So even though stromatolites show beautiful banding, we cannot be sure if the banding structure is indicative of the number of days in a year.

Sedimentary structures called tidal rhythmites, which consist of layers of sandstone or siltstone interlaced with layers of mud, record daily to yearly changes in deposition due to the daily to yearly changes in sea level associated with the tides (Williams 1989). The best preserved tidal rhythmites discovered so far are those of the Rhynella and Elatina formations, exposed near Adelaide in south Australia. These Precambrian deposits (~620Mya) record more than 60 years of tidally influenced deposition. There is a correlation between the thickness of these laminae and the height of the tide from which they were deposited. This means that an estimate of the number of lunar orbits per year can be calculated; following from this an approximate Earth Moon distance can be estimated and a mean rate of recession of the Moon can be obtained from 620Mya.

Estimates of these values from the Big Cottonwood Formation (Chan *et al.* 1994) (~900Mya) and from banded Ironstone Formation (~2450Mya) are included in Table 1.

Table 1. Earth-Moon diatance, mean rate of recession and number of days per year..

Age Mya	*0 (at present)*	*620*	*900*	*2450 * (from BI)*
Earth Moon Distance (km)	*384,400*	*370,000*	*363,000*	*345,000*
Rate of lunar recession (cm/yr)	*3.8*	*2.17±0.3*	*2.25±0.5*	*1.24±0.7*
Days per year	*365.25*	*400 ±7*	*422 ±12*	*514 ±33*

A graph of Earth-Moon distance through time based on these recession rates is shown in Figure 1.

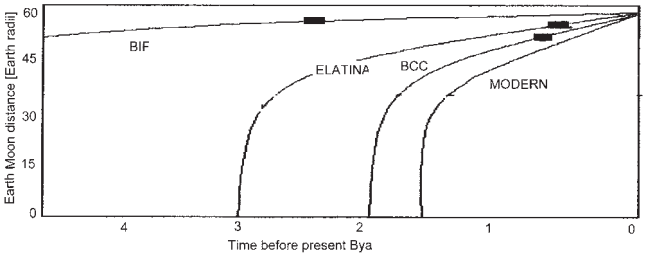

Figure 1. Comparison of computed past Earth-Moon distance based on recession rates from banded Ironstone Formation (BIF ~2450Mya), Elatina (~620Mya), Big Cottonwood Formation (BCC ~900Mya) and modern recession rates (after Williams 2000).

The nature of Neap Spring Cycles.

The Earth's orbit about the Sun, and the Moon's orbit about the Earth, produce cyclical sea level variations which we call tidal cycles. There are strong tidal cycles associated with spring and autumnal equinoxes. Within, and interacting with these cycles, are monthly cycles associated with the eccentricity of the Moon's

orbit. There are also cycles associated with the phases of the Moon and cycles associated with the Moons declination which are usually called Neap Spring cycles. They occur twice in every orbit of the Moon about the Earth. The sea level height variations associated with these cycles are recorded at tidal stations around the world. They are caused by the interaction of the tidal forces of the Sun and Moon as shown in Figure 2.

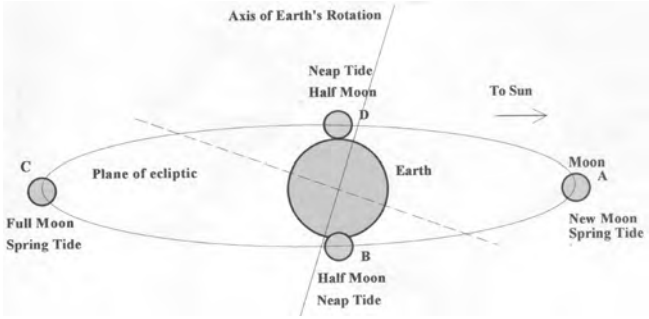

Figure 2. A simple astronomical explanation of the forces that cause Neap Spring cycles. Imagine the Sun to the right of this diagram. When the Moon is in position A and C we have spring tides, because the Sun's and Moon's tidal influence add together. When the Moon is in position B and D we have neap tides because of the opposing interaction of the tidal forces of the Sun and Moon. This type of Neap Spring cycle is associated with a semi-diurnal tidal regime.

This Neap-Spring variation in tidal height is recorded in growth increments in intertidal bivalves and in depositional thickness in sand mud couplets (Roep 1991). At present the Sun's tidal influence is around 0.46 of the Moon's tidal influence and this gives rise to a tide raising potential variation over the time of the Moon's orbit as shown in Figure 3.

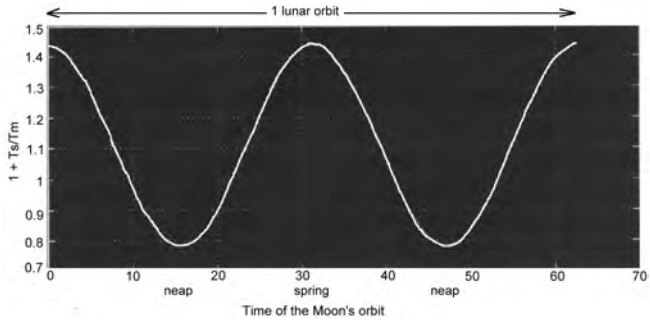

Figure 3. Tide raising potential variation.

The vertical scale on this diagram is the ratio of the tide raising potential of the Moon (Tm) and the Sun (Ts) to the tide raising potential of the Moon (Tm).

$$\frac{Tm + Ts}{Tm} \quad \text{or} \quad 1+Ts/Tm$$

The variations on either side of 1 on the vertical scale are due to the interaction of tidal forces of the Sun and Moon. The horizontal scale represents the time of the Moon's orbit (days).

Although this is a simplification (Stacey 1977), we can see that the Sun's tidal influence causes large variations in tidal potential because it is significant with respect to the Moon's tidal influence. Most modern theories of the Moon's past assume that it started out quite close to the Earth. If in the distant past the Moon was much closer to the Earth, e.g. half its present distance, the corresponding graph is shown in Figure 4.

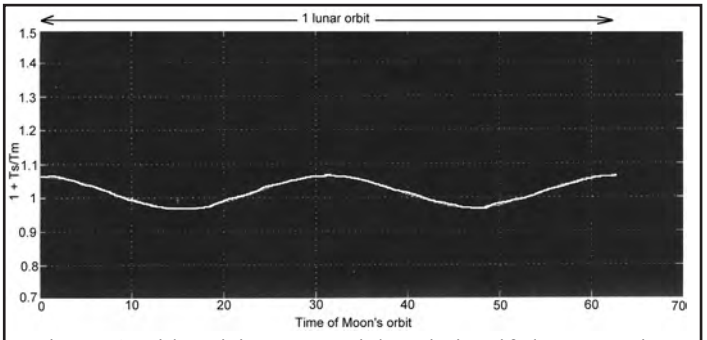

Figure 4. Tide raising potential variation if the Moon is half its present distance from the Earth.

Plotting both ratios on the same graph we get the graph shown in Figure 5.

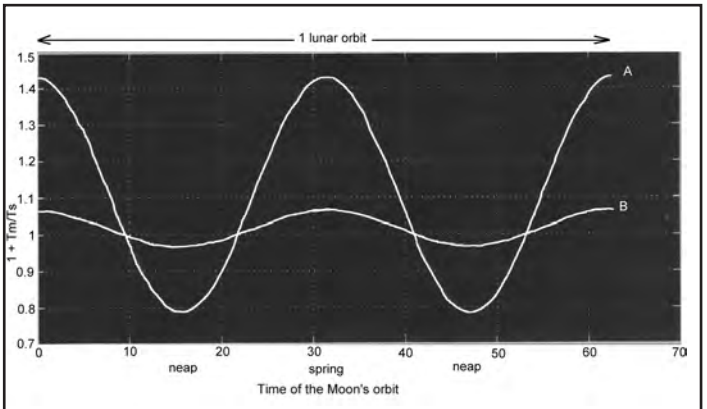

Figure 5. Neap Spring Tide force ratio.

Curve A represents the variation in the Neap Spring tidal force with the Moon at its present distance. Curve B represents the Neap Spring tidal force ratio with the Moon at half its present distance. If this analysis is correct, and if the Moon was much closer to the Earth in the past, these types of Neap Spring cycles should be difficult if not impossible to detect in the geological record. Put another way, if we can detect clear evidence of Luni-Solar Neap Spring cycles in the geological record we can give a good first approximation of a minimum Earth-Moon distance at the time. With this method we may not need many years of continuous cycles and preservation. The interaction of these Neap Spring cycles with cycles caused by the eccentricity of the Moon's orbit and with the Earth's orbit around the Sun may provide a minimum Earth Moon distance at which it would be impossible to detect Neap Spring cycles in the Geological record.

If we call this distance the Neap Spring line we can see its usefulness in the graph in Figure 6. If Neap Spring cycles were detected in Early Archaean rocks it would place the Earth Moon distance above the Neap Spring line and have implications for theories on the origin of the Moon. Tidally influenced structures have been found in rocks as old as 3300My but so far no Neap Spring structures of this age have been discovered. The oldest example of presumed Neap Spring structures are in chert nodules in the Weeli Wolli banded ironstone formation in the Hamersley Basin, Western Australia (Williams 2000).

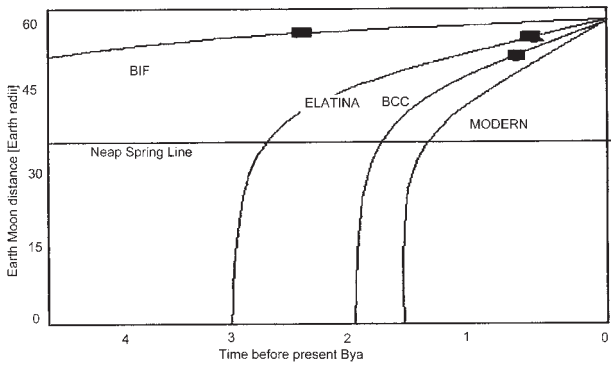

Figure 6. If luni-solar neap spring evidence is found >3Bya we may automatically assume a minimum Earth-Moon distance.

Irish Tidally influenced sediments

I will finish with one example of a tidally influenced facies from the southwest of Ireland. In the field it is best described as a pin-stripe laminated facies. But in hand specimen and in thin section it reveals details of a tidal origin (Figures 7, 8 & 9).

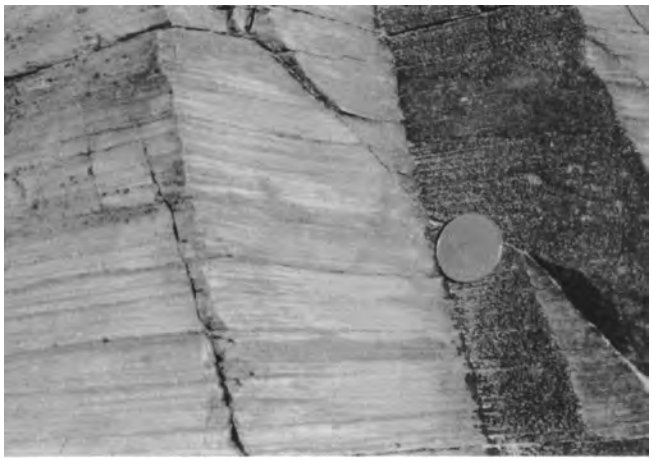

Figure 7. Pinstripe Laminated Facies from the Dunquin Group in southwest Ireland.

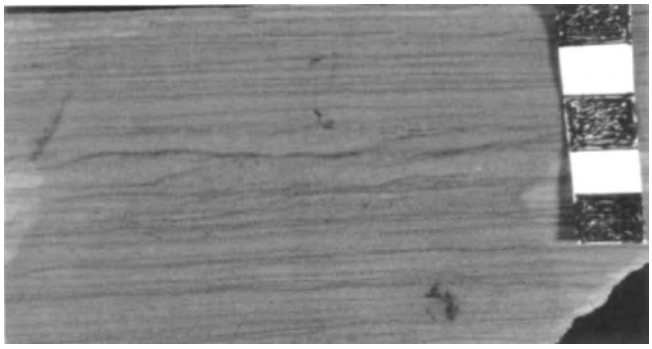

Figure 8. Polished hand specimen showing fine laminations. Are they tidal?

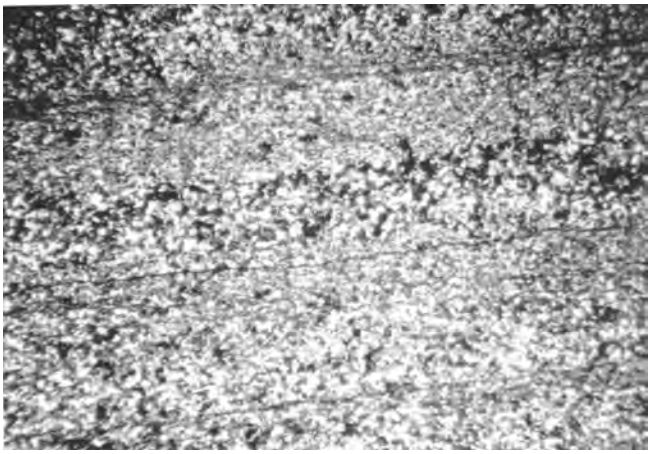

Figure 9. Thin section (X20) showing fining upward sequences of silt into mud which is indicative of low energy tidal deposition.

References

Chan M A, Kvale E P, Archer A W & Sonett C P, 1994. Oldest direct evidence of lunar–solar tidal forcing in Sedimentary rhythmites, Proterozoic Big Cottonwood Formation, central Utah, *Geology* **22**, 791-794.

Evans J W, 1972, Tidal growth increments in the cockle *Clinocardium nuttalli*, *Science* **176**, 416-417.

Jones C H, 1981, Periodicities in Stromatolite lamination from the Near Proterozoic Hearne Formation. *Palaeontology*, **24(2)**, 231-250.

Mohr R E, 1975, Measured periodicities of the Biwabik (Precambrian) stromatolites and their geophysical significance. In: Rosenberg D & Runkorn S K (eds), *Growth Rhythms and the History of the Earth's Rotation*. Wiley, London, 43-56.

Pannella G, 1975, In: Rosenberg D & Runkorn S K (eds), *Growth Rhythms and the History of the Earth's Rotation,* Wiley, London, 43-56.

Roep T B, 1991, Neap-spring cycles in a subrecent tidal channel fill (3665 BP) at Schoorldam. N. W. Netherlands, *Sedimentary Geology* **71**, 213-230.

Scrutton C T, 1978, Periodic growth features in fossil organisms and the length of day and month, In: *Tidal Friction and the Earth's rotation,* 1, P Brosch & J Sundermann (eds), Springer-Verlag 259-274.

Stacey F D, 1977, Physics adapted from Gravity and tides, In: *The physics of the Earth*, 73-105. I have assumed that the lunar tidal force is constant beneath the moon and have changed the solar tidal force with the position of the Sun relative to the Moon as the Moon orbits the Earth. This model demonstrates the dramatic effect on the tide raising potential and Luni-Solar Neap Spring Cycle if, as current theories suggest, the Moon was at one time much closer to the Earth.

Vanyo J P, 1985, Stromatolites and Earth Dynamics. *Precambrian Res*. **29**, 121- 142.

Wells J W, 1963, Coral growth and Geochronometry, *Nature* **197**, 948-950.

Williams G E, 1989, Tidal rhythmites: geochronometers for the ancient Earth-Moon system, *Episodes* **12**, 162-171.

Williams G E, 2000, Geological constraints on the Precambrian history of the Earth's rotation and the Moon's orbit. *Reviews of Geophysics* **38**, 37-59.

Application of resistivity geophysical techniques to contamination studies

Dorothy M George & Paul J Gibson, Department of Geography, National University of Ireland, Maynooth, Co Kildare, Ireland.

Abstract

Geophysical techniques are increasingly being used in environmental investigations, including landfill sites, where the possibility of leachate movement and groundwater contamination are of primary importance. Resistivity surveys are carried out using systems such as the Campus Geopulse with specific electrode arrays to obtain apparent resistivity measurements. The data are then computer modelled using an inversion program in order to produce either a 2-D or a 3-D contoured image of the true depth and true resistivity. The profiles produced are interpreted to give the depth and boundaries of landfill, and to detect any leachate plumes and movement into layers below and/or adjacent to these boundaries.

Studies of former landfill sites in Co Monaghan still have low resistivity indicators 17 years after closure. Leachate from disposal of spent mushroom compost is also a potential source of contamination to groundwater and streams in the area.

Applications of resistivity

Resistivity is a geophysical technique which can be used to model the subsurface in the following applications :–

Search for suitable groundwater	
Monitor groundwater pollution	- leachate from landfill
	- saline waters
Downhole logging	
Archaeology	
Geological mapping	
Mineral exploration	
Engineering surveys	- to locate subsurface cavities
	faults
	fissures
	permafrost
	mineshafts
	water table

This is not an exhaustive list. This talk will concentrate on landfill applications and possible leachate into groundwater and water courses studied in Co Monaghan, Ireland. The research was funded by the EU under Interreg 4 (Ireland 94/99 programme).

Resistivity method

Ohm's Law describes resistance as a relationship between potential difference (voltage) and current according to the equation

Resistance = voltage / current

$$R = V / I$$

Measurements indicate how easily a wire will transmit an electrical current. However, the resistance of a wire varies according to the length (the longer the wire, the higher the resistance), the thickness (the thinner the wire, the higher the resistance) and the type of material from which it is made. These problems are overcome by measuring resistivity (ohm metre, Ωm) rather than resistance (ohm,Ω) as resistivity is independent of the geometry of the wire.

'True' resistivity = resistance x cross-sectional area/length of wire

$$\rho = RA / L$$

The equipment used measures the 'apparent' resistivity shown by the equation:

'Apparent' resistivity = measured resistance x geometric factor

$$\rho_a = RK$$

The geometric factor, K, takes into account the geometric spread of the electrodes and type of array used. In this study the Wenner array was used and is explained below. The resistivity equipment consists of a multicore cable connected to a switching module in the Campus Geopulse control unit, which in turn is connected to a field laptop computer to automatically record the readings. Take-off points along the cable are connected to 25 metal electrodes at 10m maximum spacing, allowing a line of 240m to be surveyed. A small electrical DC current is passed into the ground in pulses from the control unit. In traverse mode, the first reading is taken at level 1 using electrodes 1 to 4, where electrodes 2 and 3 are potential and electrodes 1 and 4 are current. The next reading uses electrodes 2 to 5, then 3 to 6, and so on until 22 readings have been taken at level 1. At level 2, a reading is taken using electrodes 1, 3, 5 and 7, then electrodes 2, 4, 6, and 8, and so on until 19 readings have been taken at level 2. Increasing the distance between adjacent electrodes allows deeper parts of the subsurface to be investigated. At level 3, electrodes 1, 4, 7, and 10, then 2, 5, 8, and 11 are used, and so on until 16 readings have been taken at level 3. The traverses continue with fewer readings at each level down to level 8 with only one reading. V, I and R are measured, and ρ_a is computed.

Modelling of results

The modelling inversion program RES2DINV uses the apparent resistivity measurements recorded by the laptop to produce a 2-D pseudosection. This is the initial very approximate image produced by plotting each ρ_a reading on a vertical section at a point below the centre of the four relevant electrodes and at median depth. Using the inversion program to process the data and remove the geometrical effects, a model of true resistivity and true depth is produced. A calculated apparent resistivity pseudosection is produced from this model. The program goes through 5 iterations (more are possible) until there is a close match between the calculated apparent and the measured apparent.

The inverse model section delineates areas of varying resistivity along the profile to a depth of almost 32m if the full 250m cable is utilised.

Resistivity surveys in Co Monaghan

Miller & Guzzwell (1999) have demonstrated that resistivity and conductivity techniques are effective in indicating the leaching and flow of contaminants. Resistivity was one of the geophysical techniques employed during September and October 1999, to determine the boundaries of two former landfill waste disposal

sites and to monitor the existing site operated by Monaghan County Council.

Figures referred to in this presentation are taken from George and Gibson (2000). To aid interpretation of survey profiles, the ranges of resistivities for various subsurface materials are given in Table 1 below.

Table 1 : Resistivities of selected geological and other materials. Source: modified after Reynolds (1997)

Material	Nominal resistivity (Ωm)
Granite	3×10^2 to 10^6
Gabbro	10^3 to 10^6
Sandstones	1 to 7.4×10^8
Limestones	5×10 to 10^7
Clays	1 to 10^2
Alluvium and sand	10 to 8×10^2
Moraine	10 to 5×10^3
Gravel (dry)	1400
Gravel (saturated)	100
Sand and gravel	30 to 225
Unsaturated landfill	30 to 100
Saturated landfill	15 to 30
Rainfall runoff	20 to 100
Landfill runoff	<10 to 50

Five survey lines showed that the shape of the former landfill site near Smithborough could still be delineated by resistivity techniques even 17 years after waste disposal ceased and the site filled, levelled and returned to agricultural use. The underlying bedrock in the area is the Cooldaragh Formation (Carboniferous Dinantian), a silty mudstone (Geological Survey of Ireland, 1997). A profile example is shown in Figure 1, which is interesting for three reasons. Firstly, it contains the lowest value of the whole study, only 3.07Ωm. Low values are indicated from 0–205m and to > 20m depth, making uninterrupted flow possible towards streams bordering the field. Secondly, undisturbed solid rock is shown to be horizontal from 25m to the base all along the section. Thirdly, from a point of general interest, the line crosses the course of the former Ulster Canal, whose shape is visible near the surface at 100-110m.

Co Monaghan has numerous glacial landforms. The former and present landfill sites near Scotch Corner have taken advantage of this, with waste being disposed of in a glacial lough depression. The underlying bedrock is the Lough Avaghon Formation, a massive sandstone and microconglomerate of the Ordovician/Silurian Central Belt (Geological Survey of Ireland, 1997). The former site is a green field, having been levelled and returned to agriculture. No remnants of its previous use are visible, although at the time of the survey the ground was found to be very wet with rushes growing in places and bubbles of gas escaping, even 6/7 years after use. As for the Smithborough site, the modelled sections for the five survey lines taken clearly define the vertical and lateral extent of the filled area. A representative profile is shown in Figure 2. There is an abrupt change at about 120m from high values (maximum of 6913Ωm) indicative of bedrock to low values (minimum of 9.48Ωm) close to the surface, indicative of saturated/unsaturated landfill. The lateral extent of the former landfill site is clearly defined. A Geonics EM31 conductivity grid survey was carried out at this site and confirmed the resistivity findings. Conductivity is the inverse of resistivity, with high values indicating a good conducting material. The landfill area was characterised by high conductivity values due to a combination of metals and leachate within 6m of the surface. There was a sharp boundary defined between this and the surrounding undisturbed ground, which showed low conductivity values. The original depth and initial shape of the disposal site were unknown, so it was difficult to say whether there had been movement of leachate material into the adjacent subsurface, although there was some indication of an extending plume.

Three survey lines were conducted at the boundaries of the present landfill waste disposal site. The section in Figure 3, taken at the base of an existing cell, shows very low resistivity over the whole length and depth to 15.9m, consistent with saturated landfill. The start of the section is beyond the extent of the cell. Values range from 10.29 to 1542Ωm, with an anomalous zone of higher resistivity at 62.5m and 4m depth possibly representing a drainage pipe. At the time of the survey, a new waste cell was under construction. Unlike existing and previous cells, this one was to be lined in order to meet Environmental Protection Agency (EPA) standards. It would be possible to incorporate resistivity cables at the base of the cell below the membrane in order to monitor whether any future leachate plumes began to extend from the cell, indicating the appearance of holes in the membrane.

Co Monaghan is a main mushroom producing area of Ireland, and there is a problem of what to do with the large amounts of spent compost. One solution is to dispose of it in and around lough depression areas, but the possible effects of leachate draining from it into ground and surface waters is a potential problem. Three survey lines were conducted at one such site north of Monaghan town, where the underlying rock is the Dartry Limestone Formation, a dark fine-grained cherty limestone of Carboniferous Dinantian age (Geological Survey of Ireland, 1997). Resistivity values for the modelled sections ranged from 14.38 to 449Ωm, with one line having the lowest maximum resistivity value of the whole study of 144Ωm. These are values of low resistivity similar to known landfill sites, so the deposits of spent compost could be the source of possible contamination.

Conclusions

The resistivity surveys carried out at the four sites successfully modelled the subsurface shape of the landfill areas, both current and long since disused. Detected anomalies indicate that leachate is probably still present within the subsurface, so this study provides a benchmark to allow the situation to be monitored in the future. Any change in the subsurface conditions and lateral extent could be followed. The study also showed that, if already wet areas are used for the disposal of spent mushroom compost, there is potential for contamination of groundwater and adjacent streams. Monitoring such sites at regular intervals will track an improvement or worsening of the situation.

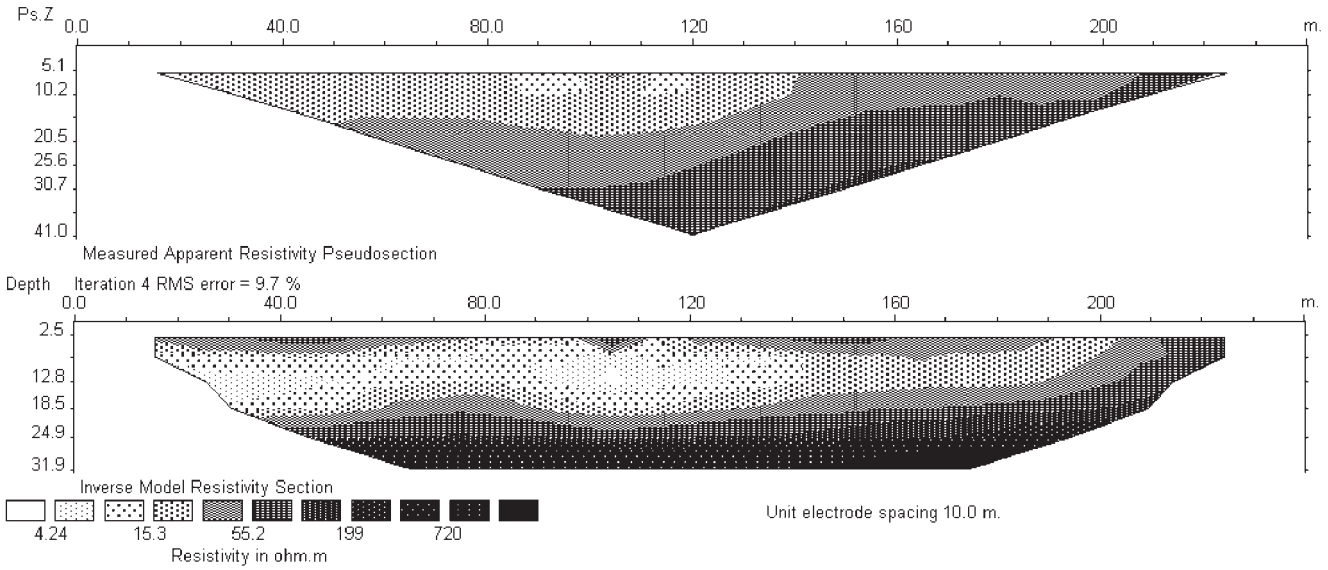

Figure 1. Resistivity profile - former landfill site near Smithborough, Co. Monaghan

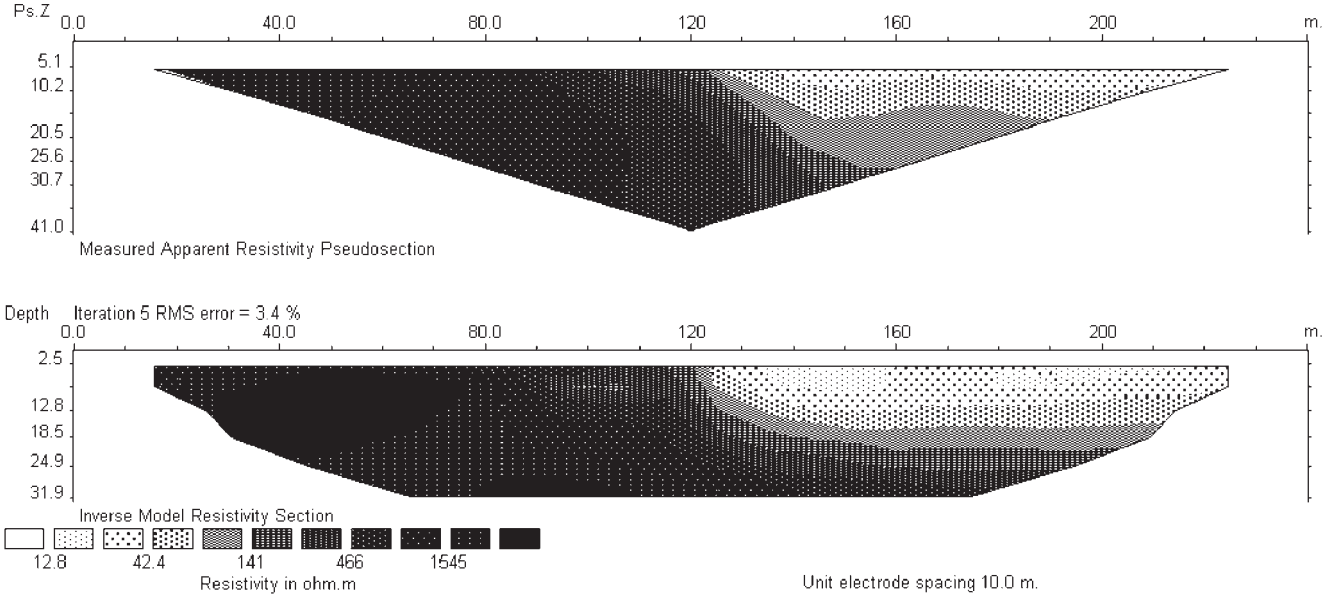

Figure 2. Resistivity profile - former landfill site near Scotch Corner, Co. Monaghan

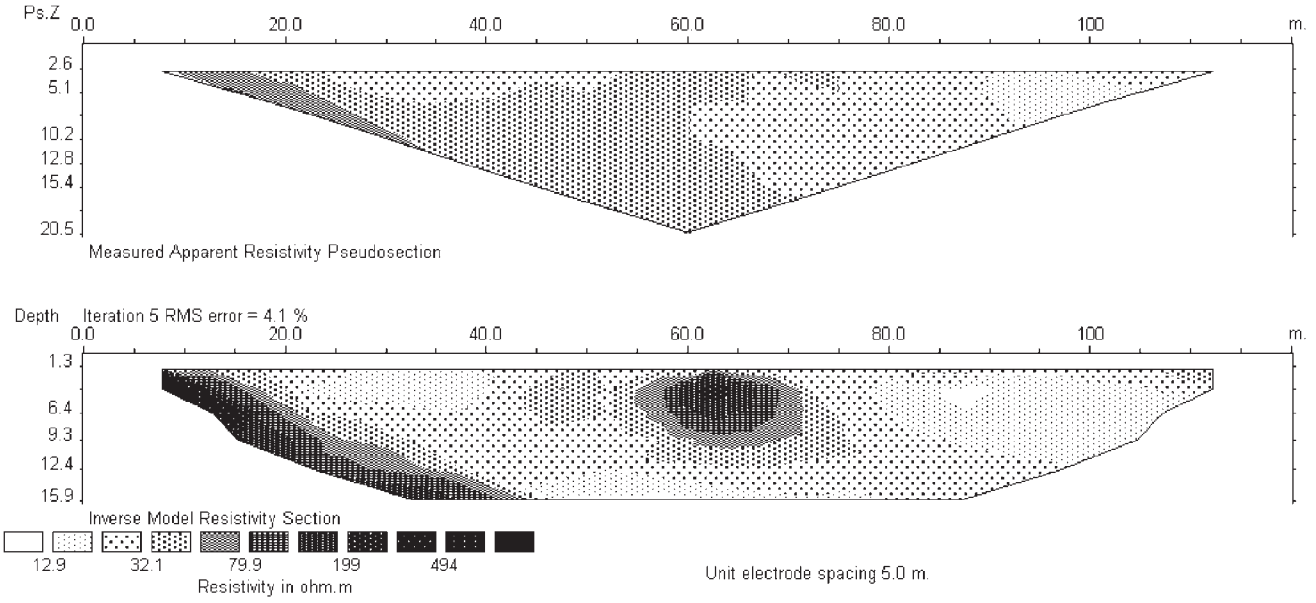

Figure 3. Resistivity profile - present landfill site near Scotch Corner, Co. Monaghan. Ps.Z - Pseudosection depth.

References

Geological Survey of Ireland, 1997. Geology of Monaghan-Carlingford. 60pp and 1:100 000 Sheet 8 and part of Sheet 9 map.

George D M & Gibson P J, 2000. *Application of Geophysical Techniques for Groundwater Investigations and Waste Disposal Site Contamination Studies in Co Monaghan, Republic of Ireland.* Report No: EGU001/2000.

Miller H G & Guzzwell G K, 1999, Geophysical Mapping of a Shallow Contaminant Plume in Thin Glacial Till, Northeast Newfoundland. *Journal of Environmental & Engineering Geophysics* **4,** 241-249.

Reynolds J M, 1997, *An Introduction to Applied and Environmental Geophysics.* Wiley, 796 pp.

Book reviews

Restoration Ecology and Sustainable Development, K M Urbanska, N R Webb & P J Edwards (eds), 1997, Cambridge University Press, 397 pp, £55.00 (hardback), ISBN 0521581605.

This book is a compilation of papers presented at the first international conference on restoration ecology held in Zurich in 1997 and is set out in five parts. These are: 1 Introduction (two papers); 2 Ecological basis of restoration (six papers); 3 The implementation and assessment of restoration schemes (six papers); 4 Ecological restoration, economics and sustainability (two papers) and 5 Conclusions (one paper).

There is a need to inform those involved in mineral extraction of how to minimise damage to the local environment and speed restoration. Accessible papers are in the minority. Many of the writers are heavy going even for a semi-ecologist and seem determined to obfuscate rather than inform. The pedantic vocabulary shuts out the non-ecologist with phrases such as "propagules of the invasives will continue to rain on the site and represent an ongoing contextual process" or "which combine subterranean diaspore production and virtual achory with above-ground dispersal".

For the geologist, Bradshaw on "The importance of soil ecology in restoration science" and Webb's "The development of criteria for ecological restoration" are probably the best. Haselwandter, on the importance of "Soil micro-organisms, mycorrhiza and restoration ecology", covers an area vital to successful site rehabilitation but assumes knowledge lacked by many non-biologists although much can be inferred from context. Information on storing topsoil to increase the survival of beneficial micro-organisms and on stockpile design to promote the survival of a viable fungal component is useful. Handel covers plant-animal mutualisms stressing that sustainable site restoration means a viable ecosystem, not just plants.

Part 3 is much more accessible. The papers that cover restoration in the United States (Chambers), Iceland (Magnusson) and the role of arthropods (Williams) demonstrate what is possible even to the geologist. Majer argues the importance of invertebrates in the restoration process using a number of mine sites as examples and covers various difficulties including the problems of pit fall traps (for ants!) which undersample "cryptic, hypogaeic, arboreal and rare species". I am now looking out for cryptic or hypogaeic ants! Neiring's fascinating paper on wetland restoration, which is relevant to coastline and flood management in the UK, uses accessible language whenever possible, botanical names excepted.

Parts 4 and 5 also make interesting reading but the reader has to have the strength of will to get there! I would only recommend this book to a research student studying site restoration and then as a reference not as a major text.

Penelope JL Reid, BSc (Open) BSc (Hons)

Pleistocene Amphibians and Reptiles in Britain and Europe by J Alan Holman, 1998, Oxford University Press, 254pp, £50 (hardback) ISBN 0195112326.

This is intended to be a companion to the sister volume Pleistocene Amphibians and Reptiles in North America by the same author. The book begins with an overview of the Pleistocene and a discussion of the variations in pre-Pleistocene herpetofauna largely as a result of climate change. Of the early chapters, the review of the chronostratigraphy of the Pleistocene may be useful to those with more than a passing interest in Pleistocene chronology.

A large portion of the book is devoted to a 'Bestiary' which is a catalogue of the Pleistocene herpetological taxa of the region. The 'Bestiary' consists of taxonomic accounts of Pleistocene amphibians and reptiles with drawings of diagnostic skeletal elements. Habitats and distribution of modern taxa that occur in the Pleistocene are also included. This is a useful summary of the herpetofauna and the starting point for any research on Pleistocene amphibians and reptiles. Further work on any of the fossil material will require following up the large number of references provided.

A description of fossil localities follows. Fossil localities are numbered and described by area and age. The interpretive section begins with a discussion of herpetological species as palaeoenvironmental indicators and population changes as a result of Pleistocene events. Short discussions of the palaeoenvironment of the sediments is given based on the herpetofauna. It is argued that herpetological species are good indicators of temperature/climate because of their sensibility to temperature change. Moreover, most Quaternary reptiles and amphibians are composed of species which exist today so that habitat preferences are known with some certainty. The book concludes with a dialogue about the apparent stability of the Pleistocene herpetofauna compared to mammalian and bird populations and comparisons with North America.

The book is meant to be a 'college level' introduction and is a standard reference for anyone interested in Pleistocene fauna as well as Pleistocene events in general. It would also be useful for modern herpetologists. It is a specialised book mainly of interest to those embarking upon Pleistocene research. The use of herpetofauna fossil assemblages to trace advancing and retreating ice sheets is an interesting new slant on palaeoclimatology for me. At a price of £50, readers with only a casual interest in the subject would be advised to consult a library copy.

Dr Alan Seago, PhD, BSc Hons Geology, OU Tutor

Discovering Geology: Fossil Focus – Crinoids by Mark Woods, 1999, BGS, A3 folded, £1.95, ISBN 085272330X

At first glance this is an attractive looking pamphlet which is both pleasing to the eye and offers a promise of being very informative; I am pleased to announce that this actually proved to be the case. The contents are easily read, written in a language that is readily understood by children from the age of 8 to 80, and an enjoyable use of one's time.

The technical terms were kept to a minimum yet the scientific facts were not lost; the author describes the fossil assemblages well and manages to place the fossils into the appropriate eras and periods without confounding the reader. With high quality graphics, both photographic and painted, which illustrate the author's points well, the reader is treated to an informative and pleasing experience.

I believe that the pamphlet will be equally great for the amateur palaeontologist as a reference and for those with an interest in fossil hunting. I also believe that it would be an ideal introduction in a school environment to inspire children during one of their fossil 'projects'. It is accessible and shows that not all fossils of interest were over 50 feet long and weighed several tons!

The author has successfully produced a very useful guide to crinoids, one which can easily be referenced, and a more than satisfactory addition to anyone's collection of palaeontological literature.

C J Applebee BSc (Hons)

Is there a close relationship between aplites and microveins in the Leinster Granite?

Susan Pyne, Department of Geology, National University of Ireland, Belfield, Dublin

Introduction

Aplites (Figure 1) occur with pegmatites in the roof zone of many granites. In this respect the Leinster Granite (Figure 2) in south-east Ireland is typical. The Leinster Granite is the largest exposed granite mass in either Ireland or Britain covering an area of over 1,500km^2. It is a peraluminous, two-mica granite of Caledonian age (405Ma). The granite is enclosed in a thick sequence of Lower Palaeozoic deep-water basinal sediments (McConnell & Philcox 1994) and volcanics of Cambrian to Ordovician age.

Figure 1. Typical aplite vein (~30mm wide) in Leinster Granite (hand lens topleft of photo for scale).

Although much work has been carried out on pegmatites, there has been significantly less work on aplites. Because of this, there has been no satisfactory explanation of how aplites came to be where they are or where they came from. The origin of aplites and their relationship with the pegmatites remain enigmatic. However, microveins observed in Leinster Granite may have a bearing on their origin.

Aplites and pegmatites

Aplites and pegmatites, commonly found as veins, are quite reasonably described as late stage fluids in a cooling granite. They are typically of minimum-melt composition consisting of mixtures of quartz and alkali feldspar; they may or may not contain muscovite.

There are two major differences between aplites and pegmatites. The first difference is in the texture. Aplites are fine-grained and commonly have a sugary texture. Pegmatites, on the other hand, are coarse-grained, in some cases extremely coarse-grained with crystals many metres long.

The second difference between aplites and pegmatites lies in their accessory minerals. Aplites commonly have two minerals associated with them, boron-bearing tourmaline and the manganese-bearing garnet, spessartine. Pegmatites are noted for the wide range of exotic minerals associated with them, such as beryl, topaz, spodumene, wolframite or tanatalite. Pegmatites have long been a source of economic minerals, a major reason why they have been the more studied of the two rock types.

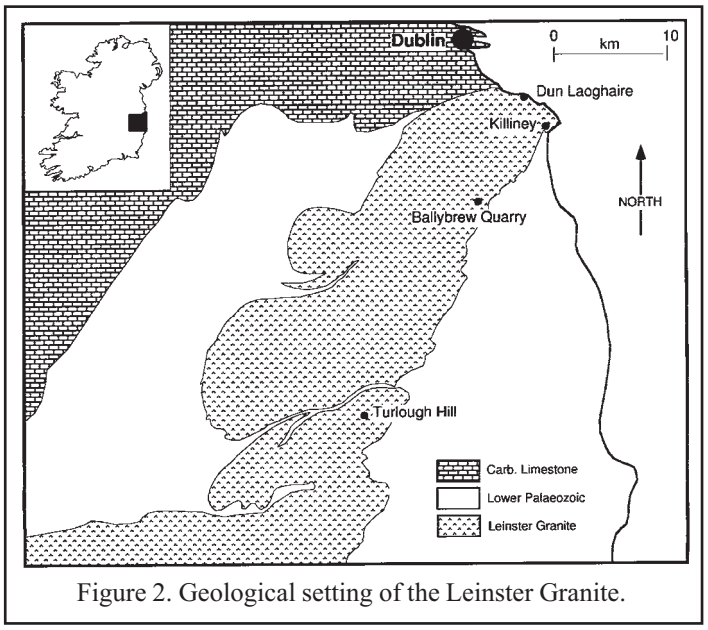

Figure 2. Geological setting of the Leinster Granite.

The explanation commonly given for the difference in grain-size, and probably for the mineral content, is the presence, or absence, of volatiles. Volatiles, including water, carbon dioxide, boron and fluorine, act as fluxes which help a granite magma to flow. It has been suggested that the sudden loss of volatiles, resulting in a sudden loss of temperature, may initiate crystallization in an aplite. Alternatively, if the volatiles are trapped within the melt they may assist the slow crystallization of a pegmatite. Volatiles may also help in the transport of unusual elements, producing the exotic minerals that are found associated with pegmatites.

Microveins

Microveins in the Leinster Granite were first recognized in dimension stone, originally from a quarry at Ballybrew in Co. Wicklow. The slabs, each approximately 1200mm x 700mm, were used as granite cladding on the Science Buildings on the Belfield campus of University College Dublin (UCD) (Figure 3).

The microveins are extremely difficult to see at first (Figure 4) and it was only because the surfaces of the slabs are smooth that the microveins were first observed. Microveins are virtually impossible to see if there is any roughness at all on a granite surface, and have never been observed in outcrop by the author.

The microveins are aplitic in composition, with most containing only quartz and feldspar; however, their grain-size is similar to the host granite. The microveins appear in a granite that was obviously acting in a brittle manner, as demonstrated by the microfractures in the granite, yet fluid was clearly available to move into these fractures. This points to a transition between

Figure 3. General view of the granite cladding on the Science Buildings in University College Dublin.

fluid and brittle behaviour in the granite. It has been suggested that this transition occurs when the granite magma is 65-70% crystallized and 30-35% melt (van der Molen and Paterson 1979; Pitcher 1997).

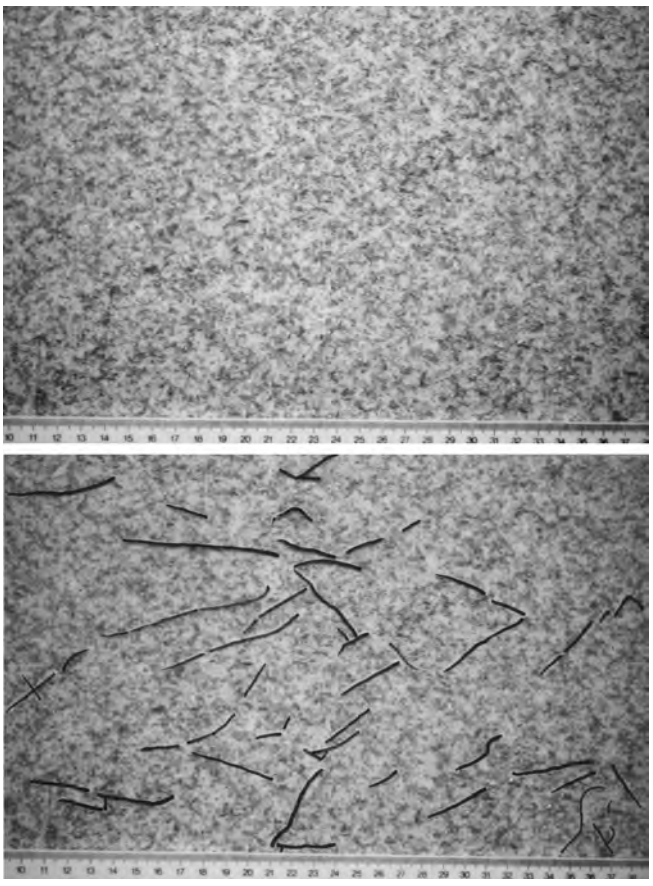

Figure 4. Microveins on a slab and a hand drawing showing the distribution of some of the microveins.

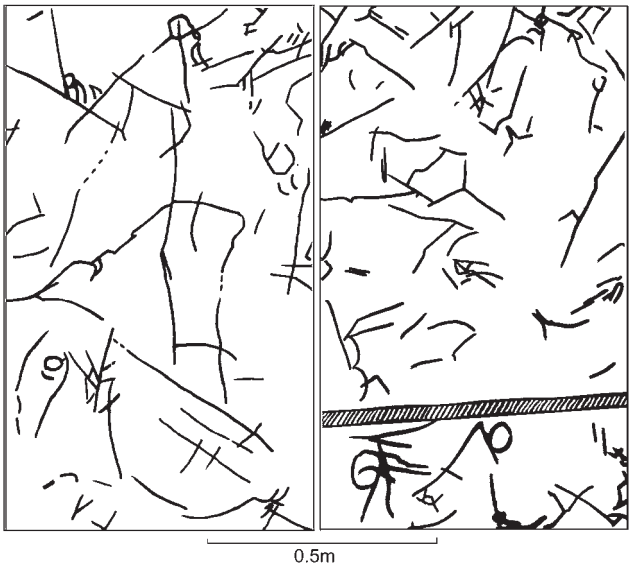

Figure 5. Hand drawings showing distribution of microveins on two slabs and the size of the estimated vein material locked up in the microveins. Widths of the microveins are exaggerated.

Drawings were made of several slabs showing the distribution of microveins e.g. Figure 5. There are two points of particular interest. Firstly, the microveins are relatively short, with an average length of 86mm and secondly, the microveins form a disconnected network.

Working from the drawings, estimates were made of the amount of liquid locked up in the microveins of several individual slabs. Multiplying the total length of microveins on a particular slab by their average width of 2mm generated a theoretical vein 29.4mm wide across the 700mm width of the slabs, which is almost 2.5% of the total area (Figure 5). Thus, a substantial amount of residual fluid is represented by the microveins.

A further calculation used the total area of the slab divided by the number of microveins on the slab to produce the average area allotted to each microvein. If this average area is then considered as the area of a circle, the diameter of that circle represents the minimum length of microvein required to form a connected network of microveins on the slab (i.e. any microvein longer than this will, in theory, intersect another microvein). This minimum length for a connected network came to 94.5mm, just 10%longer than the average microvein length of 86mm. In a cooling granite that is just beginning to fracture in a brittle manner, it is quite feasible that fluid-filled microveins could be extended by an extra 10% and form a fully connected network. Should a significantly larger fracture then cut across this network, fluid would be drawn, or forced, into it. The drained microveins might then close up and effectively disappear, leaving behind only the larger aplite or pegmatite veins.

The granite cladding slabs of the UCD Science Buildings were specifically selected by the quarrymen for their lack of aplite. In over 2,000 slabs not one aplite vein is seen. However, there are aplite veins in the source quarry at Ballybrew and these have similar dimensions to the computed theoretical vein. The vein from Ballybrew shown here (Figure 6) is approximately 30mm wide and has a pegmatitic edge and an aplitic centre. The relationship between the pegmatite and aplite can be explained in terms of a

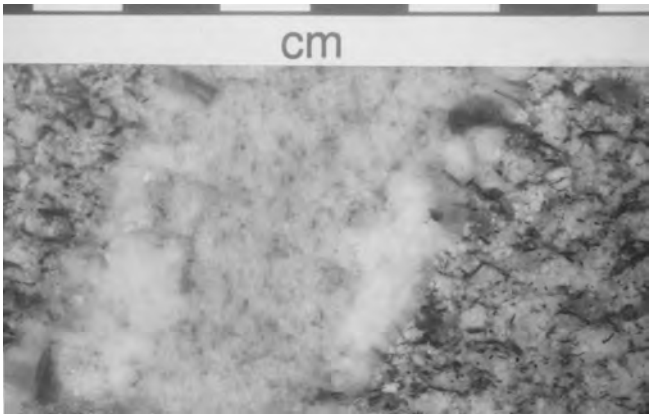

Figure 6. Composite aplite/pegmatite vein from source quarry at Ballybrew, Co. Wicklow.

closed system containing volatiles which encourage pegmatite to grow inwards from the edges. A relatively sudden loss of volatiles, perhaps through a new fracture opening, could then lead to the remaining fluid in the vein crystallizing rapidly to produce the aplite centre. However, many other relationships between aplite and pegmatite are more difficult to explain.

Could the opening of seemingly insignificant fractures, as revealed by the microveins, be the process that initiates fluid flow within a solidifying granite? Perhaps many late-stage mineral changes due to fluid migration begin at this time; mineral changes such as the development of myrmekite or changes in the composition of feldspars and micas.

Conclusions

Aplites (and pegmatites) occur at a time when a granite magma is in transition between ductile and brittle behaviour. The granite is beginning to fracture, as demonstrated by microveins, yet residual fluid is still available to flow into the space made available. Microveins may be the precursors of aplites and pegmatites and may represent the first stage in the extraction of fluid of aplitic composition from a granite. By forming a connected network, microveins could drain into larger fractures that might intersect this network. Once the fluid has drained from the microveins they could close up and effectively disappear.

Microveins were first observed on granite cladding slabs on the Science Buildings in UCD, which were selected because they do not contain aplite (or pegmatite) veins. These slabs have disconnected, two-dimensional networks of felsic microveins which occupy ~2.5% of the total area of the slab, enough to produce a vein almost 30mm wide across the slab. Thus, there is sufficient material contained in the microveins to produce aplite veins of a reasonable size such as occur in the source quarry.

The presence or absence of volatiles can explain some of the many relationships between aplites and pegmatites. Fractures opening, or becoming blocked by congealed material, could control this presence or absence.

Fracturing on a small scale, as represented by the microveins, may initiate the migration of residual fluid within a granite to produce late stage textural changes, such as myrmekite.

References

McConnell B & Philcox M E, 1994, *Geology of Kildare - Wicklow. A geological description to accompany the bedrock geology 1:100,000 map series, Sheet 16, Kildare - Wicklow.* Geological Survey of Ireland, Dublin. 69pp. + map.

van der Molen L & Paterson M S, 1979, Experimental deformation of partially-melted granite. *Contributions to Mineralogy and Petrology,* **70**, 299-318.

Pitcher W S, 1997, *The nature and origin of granite*. Chapman & Hall, London. 387pp.

Book review

Unfolding our Universe by Iain Nicholson, 2000, Cambridge University Press, 294pp, £24.95 (hardback) ISBN 0521592704.

Unfolding Our Universe is a book I would be happy to add to my shelves. In fact I have added it to my shelves. At £24.95 I feel it is a bargain. As the frontispiece says it is a comprehensive and accessible introduction to astronomy.

Plainly, the author has an abiding and authoritative interest in his subject. He was Principal Lecturer in Astronomy at Hertfordshire University and published exhaustively on astronomy. He covers the subject from fundamentals to frontiers and presents it in a way which appeals to all levels of skill and interest, from 'Absolute Beginners' to those whose own skills in the subject are well advanced.

The book is very well illustrated with photographs, charts and figures of all kinds; there's not a page without something to catch the eye. Original illustrations are by Mark McLellan from Iain's (sometimes very) rough sketches.

The format of the book makes it easy to read from start to finish. It is also easy to dip into at any point though it is not so easy to then stop at that point. There is an excellent glossary and index. The font is sufficiently sized and clear that I can read it easily; an essential, in my opinion, for any book on any subject. There are sixteen chapters ranging from an Overview of the Universe to Cosmology, Beginnings and Endings. They range through Stars, Planets, Births and Deaths and Life Cycles. There are star maps, colour photographs from many sources, well explained and uncluttered diagrams, appendices of information on measurements and physical constants, solar system data and 'The Brightest and Nearest Stars'.

Chapter 8 is The Sun: Our Neighbourhood Star. There are twelve photographs and eight diagrams and much detailed explanation in the text. It begins: "Although in all respects an ordinary and unexceptional star, the Sun ... is the only star whose features and characteristics can be studied in depth and detail". It then goes on to cover solar energy, its sources and dispersal, the neutrino problem, helioseismology, the sun's surface and atmosphere, sunspots, chromosphere and corona, spicules, filaments and prominences, flares and mass ejections, structures and solar wind and the solar cycle. Even I had some grasp on the diagram on the "predominant mode of the proton-proton reaction", again illustrated in colour. The colour pictures of the sun and its flares certainly gave an indication of the power of this unexceptional star. All the chapters follow this pattern.

A photograph on page 107 of the comet Hale-Bopp brought instant recall of a cold clear night when I had been to Worth Matravers, in the Purbecks, for a presentation of some sort. I drove all the way home to Dorchester with Hale-Bopp in view. The photograph is in Chapter 7 on Wandering Fragments: Minor Members of the Solar System. The only difficulty with this book is that a reader could well find himself or herself drawn inexorably into further exploration of the subject.

Doreen Smith BSc (Open)

The Volcanology of the Tertiary Antrim Lava Group

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The interpretation of basalt successions that have suffered the ravages of weathering and erosion over a prolonged period of time is a perennial problem for those basalt petrologists who work outside regions of current or recent volcanic activity. The basalts covering around 2500km^2 in northeast Ireland are Tertiary in age, about 60-65Ma old, and show signs of extensive post-eruption changes, including ubiquitous development of zeolite minerals in vesicles and on joint faces. These secondary, post-eruption changes tend to obscure, if not obliterate, much of the evidence which allows interpretation of the precise nature of the environment of eruption of a lava flow, including the form of the flow itself. In view of this it is a considerable advantage to be able to examine ancient lava forms, having had some experience of recent or current volcanic activity. Deciphering ancient volcanics without the benefit of recent volcanics is almost like trying to interpret fossils without knowledge of current biology.

This article aims to examine some features of modern volcanic landforms mostly from Iceland and Hawaii, and to show how they relate to features recognised in much older, Tertiary volcanic areas. It is an exercise in uniformitarianism. Icelandic and Hawaiian volcanoes can be used to elucidate Antrim and Mull volcanics.

Figure 1. Binevenagh basalt lava succession.

Figure 1 shows a typical basalt cliff in the Antrim Lava Group. It is a sequence of roughly horizontal flows, with the individual flows often separated by grassy ledges. Such a view is typical not only of Antrim, but also of Tertiary basalt successions on Mull and Skye.

Figure 2 shows how the Antrim landscape would have looked 65Ma ago. The lava field here is shown just a few weeks after a major eruption with the basalt flows still cooling and de-gassing and the line of eruption vents along a fissure clearly visible. The succession in Antrim represents a whole series of these Krafla-type eruptions piled on top of each other.

Basalt lava is capable of very fluid flow and Figure 3 shows a pahoehoe lava tongue on Kilauea, Hawaii, producing a ropy or wrinkled surface as the glassy outer surface is dragged by the moving interior of the flow.

Figure 2. Lava field on Krafla volcano, northern Iceland.

Figure 3. Pahoehoe lava tongues, Hawaii.

Figure 4. Cooled ropy surface on pahoehoe lava.

On cooling this produces the very characteristic ropy surface on the lava top (Figure 4).

Figure 5. Pahoehoe surfaces in Antrim basalts.

Figure 5 shows a similar phenomenon in cross-section in the Antrim basalts, with thin oxidised crusts showing an undulatory surface.

The other common flow type seen in modern basaltic volcanoes is aa, a lava flow with a blocky top.

Figure 6. Aa or block lava, Iceland.

The typical jumble of spiny blocks which characterises aa flows can be seen in Figure 6 near the Icelandic volcano, Hekla.

Figure 7. Aa lava, weathered.

When weathered over tens of millions of years, the aa flow resembles the lava top seen in Figure 7.

Figure 8. Ash falls, Heimaey eruption.

Many volcanic eruptions include a phase where the principal activity is the production of volcanic ash. This is often in the form of fine cinder-like particles, which because they have cooled very quickly are mostly glass. Figure 8 shows the ash falls during the Heimaey eruption off the coast of southern Iceland, where the ash formed thick layers, deep enough to bury complete buildings. Volcanic glass is very susceptible to oxidation and alteration and often forms bright red horizons between flows.

Figure 9. Interflow junction, Antrim.

Figure 9 shows the top of a flow marked by a red oxidised dust horizon, and the base of the succeeding flow.

When lava flows move over forested areas, the trees are often completely burned. However, particular circumstances sometimes leave the trees as casts within the cooled lava.

In Figure 10 a drop in the level of the lava flow has preserved the trunk of this tree encased in a chilled skin of basalt.

Within the Mull Plateau Basalts is a remarkable example of a similar tree cast with the markings of the original bark preserved in the encasing basalt. See Figures 11 & 12.

Figure 13 shows the well known hexagonal columns of the Giant's Causeway in north Antrim. These columns are part of a 100m deep flow that ponded in a deep river valley which existed on the pre-Causeway basalt land surface.

The regular six-sided columns seen in the Causeway are in the lower zone of columns in a multi-tiered columnar basalt, with a

Figure 10. Tree cast, Kilauea, Hawaii.

Figure 11. MacCulloch's Tree, Isle of Mull.

Figure 12. Close up of MacCulloch's Tree, Mull.

Figure 13. Giant's Causeway.

zone of thinner curved columns above. The lower zone is termed the colonnade, the upper carved columns are referred to as the entablature, after a terminology introduced by Tomkeieff (1940). Observations on various basalt regions in the world which have multi-tiered lava flows have shown that, in all cases, river valleys have been filled by lava flows and then the surface of the cooling lava has been flooded by the water from the displaced river. (Saemundsson 1970, Lyle 2000).

Figure 14. Young basalts in southern Iceland showing colonnade entablature jointing.

In Figure 14 is the present steep-sided river valley with a strongly convex profile, seen upper left. A similar profile can be seen centre-field, which has subsequently been infilled with a later flow, seen at the right of field (Lyle 2000). The river water that was displaced by the basalt flow flooded the surface of the cooling flow and had access to the flow interior by percolation down cooling contraction cracks referred to as "master joints". See Figure 15.

The water percolating into the flow interior modifies the cooling regime and produces the narrow curved columns of the entablature; these form as a cooling front which moves downwards from the surface. Simultaneously a slower more regular cooling front is moving upwards from the base of the flow, producing the

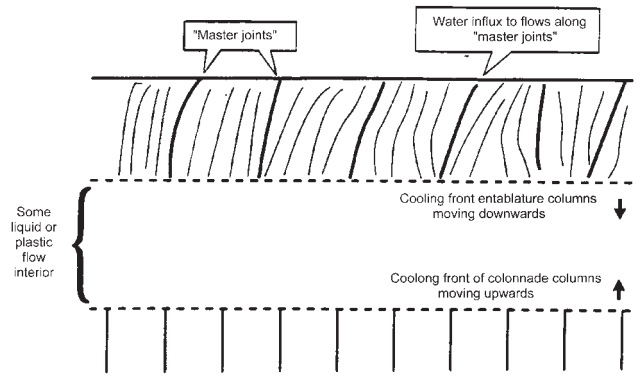
"Master joints"
Water influx to flows along "master joints"
Some liquid or plastic flow interior
Cooling front entablature columns moving downwards
Coolong front of colonnade columns moving upwards

Figure 15. Cooling pattern for multi-tier columnar flows.

hexagonal sided colonnade columns. The junction between the colonnade and entablature is where the two cooling fronts meet and is clearly seen in Figure 16 at the Giant's Organ landmark near the Giant's Causeway.

Conclusion

The application of the Principles of Uniformitarianism is as relevant to the interpretation of volcanological processes as to any other brand of geology. The study of active and recent volcanic processes can be easily shown to have a direct relevance to ancient volcanic sequences and the eruption conditions that produced them.

Figure 16. Giant's Organ, colonnade and entablature junction.

References

Lyle P, 2000, The eruption environment of multi-tiered columnar basalt lava flows. *Journal of the Geological Society, London*, **157**, 715-722.

Saemundsson K, 1970, Interglacial lava flows in the lowlands of southern Iceland and the problem of two-tiered columnar jointing. *Jokull*, **20**, 62-77.

Tomkeieff S I, 1940, The basalt lavas of the Giant's Causeway district of Northern Ireland. *Bulletin Volcanologique*, **6**, 89-143.

Book review

Building Planet Earth by R Cattermole, 2000, Cambridge University Press, 283pp, £25.00 (hardback) ISBN 0521582784.

According to the foreword, this book is aimed at the beginner with no previous scientific knowledge and claims it will be of real value to the serious student and researcher. Part One describes the planetary beginnings of Earth, Part Two the Earth's heat engine and Parts Three and Four the Earth's geological history from the Archaean to the present.

This book made me think I was reading a book from the 1970's, being out-of-date in its content, terminology and presentation. The author often makes ideas and discoveries sound far more recent and uncertain than they are. I would have expected plate tectonics to have been a much stronger theme throughout and this would have made the book more cohesive. This may partly be due to the fact that it is an update of a book published in 1985, The Story of the Earth which, by the author's admission, retains much of the material of the earlier book. The diagrams are not very good and I suspect that these have not been updated nor new ones added. In fact, one criticism of the book is that there should be many more diagrams conveying more information. There are too many wordy sections of text that are hard to follow where a good diagram would have said it all.

I find the ordering of the material particularly in Parts One and Two rather strange. If these had been more firmly based on the unifying theory of plate tectonics, the material would have naturally fallen into a better order. One result of this was duplication. For example, constructive and destructive plate margins with diagrams occur in Chapter 8 and then again in Chapter 13, where the author addresses drifting continents after starting on the geological history of the planet. There is a digression on mineralisation and hydrocarbons at constructive and destructive plate margins in the chapter on the Hercynian orogeny for some reason. His treatment of the formation of different magmas i.e. basalt, andesite and rhyolite is very vague, but there is a diagram showing the wet and dry solidus of basalt and a geotherm with no explanation in the text. Orogenesis, although crucial to the discussion of the historical geology, is dealt with in a very piecemeal way and not at all clearly. A by-product of this is that although metamorphism is repeatedly mentioned, it is also a vague concept throughout. Such basics as the rock cycle, folds and faults would have been useful, particularly for beginners.

One thing that gives the book an old fashioned feel is the constant reference to mobile belts, basins and cycles as if they have nothing to do with drifting continents (which indeed was historically the case). When dealing with the mountains of western North America he does not mention exotic terranes. It was unwise to attempt to cover the Archaean and Proterozoic unless it could be done more clearly and it did not help having a description of each Proterozoic continent in turn. Chapters 14, 15 and 16 deal with the Caledonian, Appalachian and Hercynian orogenies respectively but without explaining clearly what is going on in terms of plate movements. This could have been improved with a set of maps showing the position of the continents at various periods during the Palaeozoic. The author seems to be on firmer ground with the planetary material and geophysics which probably reflects his professional interests.

In summary, I really did not like the style of writing. It failed to enthuse and contained too much unnecessary detail. A beginner would find this book confusing and even though I am not a beginner I was also confused. I do not think this book would benefit OU students at any level. There are several books that have been published in the last 10 years covering this sort of material at this level, which are more readable, clearer and better organised

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Lower Carboniferous 'reefs' (mud-mounds) and base metal (Zn-Pb) mineralization in Ireland

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Introduction

There are two important aspects where the Lower Carboniferous rocks of Ireland differ from those in Britain and the rest of Europe: (a) extent and thickness of Waulsortian mud-mounds ('reefs') in the Tournaisian and (b) amount of base-metal (Zn-Pb) mineralization hosted in carbonate rocks. These will both be described and discussed in this paper.

(A) Waulsortian mud-mounds ('reefs')

Geographical extent and thickness

The great dimensions of most Waulsortian mud-mound complexes are known principally from large working quarries in the Irish Midlands (e.g. Ballybeg Quarry) and Dublin Basin (Feltrim, Huntstown, Bray Hill and Mullawornia) (Somerville *et al.* 1992; Lees & Miller 1995) and also from base-metal exploration in Ireland (Figure 1). The latter has involved drilling through the entire mud-mound complex to reach the base of the Waulsortian facies where many major Zn deposits have been encountered (e.g. Lisheen and Galmoy, and formerly at Tynagh and Silvermines) (Table 1).

Despite all this data, the geometries of Waulsortian mounds are still enigmatic, but in some localities (Bray Hill, Co. Meath and Mullawornia, Co. Longford) small individual lensoid mounds 5-10m high can be observed to aggregate, separated only by thin shale seams (Somerville *et al.* 1992; Lees & Miller 1995). In general, in the northern Midlands (Dublin Basin) the Waulsortian mud-banks become more isolated knolls, enveloped by argillaceous bioclastic limestone (ABL) flank facies (Somerville *et al.* 1992; Hitzman 1995a; Figure 1). However, in some quarry sections (e.g. Ballybeg) the Waulsortian mud-banks clearly assume a more tabular shape (100's - >1000's metres long and 10-20m high and pass abruptly and interdigitate with interbank and offbank facies. Sea-floor relief in some of the mounds (e.g. Knockastia, Co. Westmeath) can be tens of metres (Lees & Miller 1995).

Isopach data for Waulsortian facies (Somerville *et al.* 1992; Lees & Miller 1995) clearly shows two main elongate depocentres in the Shannon Trough and Dublin Basin, with boreholes confirming thicknesses well in excess of 500m, (>800m in the Dublin Basin) and where subsidence clearly kept pace with sedimentation (Figure 1). This establishes these Waulsortian mud-mound complexes as some of the thickest in the world (Lees & Miller 1995). Both basins show a marked NE-SW orientation and it has been suggested that in the Dublin Basin, and elsewhere in the southern Midlands, Waulsortian bank accumulation was influenced by syn-sedimentary faulting involving, in part, reactivation of earlier Caledonian faults (Jones *et al.* 1988; Somerville *et al*. 1992; Hitzman 1995a; Lees & Miller 1995). In the Shannon Trough a depositional 'sag' has been identified in the Late Tournaisian with the formation of very thick Waulsortian mud-banks, which continued as a NE-SW linear depocentre centred on the Shannon estuary throughout the Viséan and into the Upper Carboniferous. However, no overt faulting has influenced Waulsortian sedimentation (Strogen *et al*. 1996).

Composition, components and textures

Waulsortian mounds are composed predominantly of fine-grained massive pale grey limestone (lime mudstone and wackestone) with variable amount of skeletal material ('core' facies). Locally, the mounds contain crinoidal-rich packstone textures near the top. Microscopically the core facies shows a clotted texture and is often peloid-rich, especially in the geopetal sediment of cavities. The enclosing lithology is mostly thinly-bedded, crinoidal-rich argillaceous bioclastic limestone (ABL) with frequent chert nodules (Figure 1).

In the Waulsortian mounds ***stromatactoid cavities*** can locally form volumetrically a major component, with cavities occluded with initial, isopachous, inclusion-rich radiaxial fibrous cement and later blocky sparry calcite cement (Somerville *et al.* 1992; Lees & Miller, 1995). These cavities usually have an irregular digitate roof and flat base. Occasionally, fenestrate fronds may provide support for the roof. ***Sheet-spar cavities*** are sometimes recorded from Waulsortian mounds (Somerville *et al.* 1992; Lees & Miller, 1995), in which the upper and lower surfaces of cavities (with or without geopetal sediment) can be refitted. The host sediment is usually a poorly-fossiliferous lime mudstone. Such elongate, parallel-aligned cavities occur together in great numbers and are normally regularly spaced. They often can be seen to pass upward into the more irregular digitate stromatactoid cavites. These sequences develop in mounds which clearly show slumping and evidence of dewatering e.g. Bray Hill (Somerville *et al.* 1992; Lees & Miller, 1995). ***Slumping*** has been recorded in several Waulsortian complexes and at different levels within mud-mounds. It is usually more conspicuous where thin shale or clay seams separate individual lensoid mounds/banks in large quarry sections (e.g. Feltrim and Bray Hill). Related to this slumping are ***shale injections*** which occur in the massive mud-bank limestones. These shale injections can be traced vertically upwards from thin shale seams separating banks for several metres into the overlying limestone. Also, soft sediment ***limestone conglomerates*** have been recorded near the base of Waulsortian banks. These result from gravitational forces causing downslope movement of semi-cohesive muddy sediment on the steeply inclined flanks of mounds (Jones *et al.* 1988; Somerville *et al.* 1992). Sedimentary ***micrite breccias*** have also been recorded on the flanks of Waulsortian banks in Feltrim Quarry and ***graded*** crinoidal limestones have also been recorded at the top of the Waulsortian complex at Huntstown Quarry (Dublin Basin).

Fissure fills, several cm in width, are recorded in both shallow-water Viséan mounds and deeper-water Waulsortian mounds. In the Waulsortian mounds the dominant fill is laminated peloidal lime mudstone (Somerville *et al.* 1992). The laminations may be parallel or perpendicular to the walls of the fissure. Occasionally, coarse skeletal material has been recorded in fissure fills near the top of Waulsortian complexes (e.g. Feltrim Quarry). Here, large crinoid stems, goniatites and orthocone nautiloids have been found concentrated in sub-vertical fissures (***neptunean dykes***) which show cross-lamination (Somerville *et al.* 1992). This con-

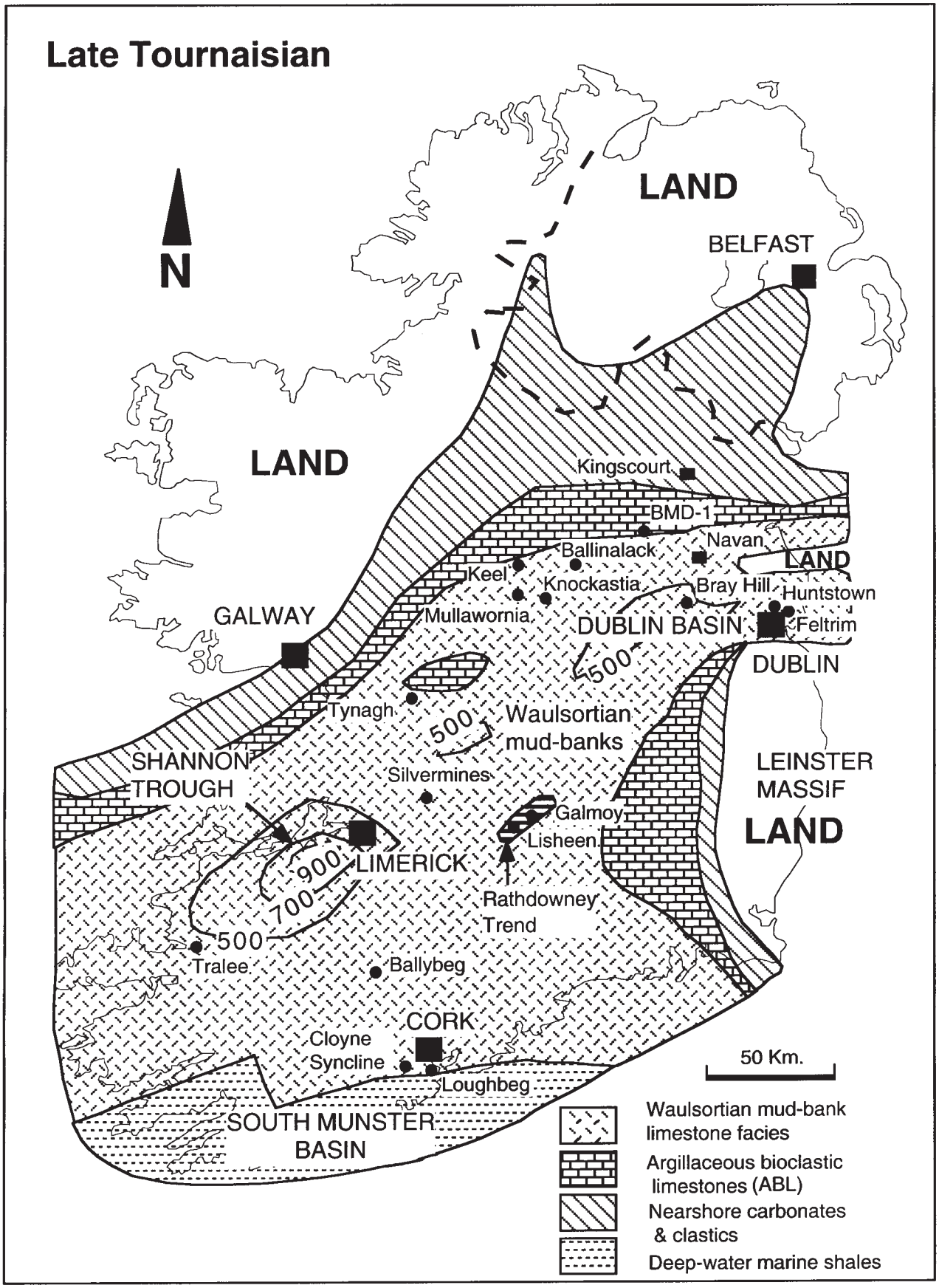

Figure 1. Generalized palaeogeographic map of late Tournaisian rocks in Ireland, showing main lithofacies and geographical extent of Waulsortian mud-bank facies and the location of quarries and boreholes referred to in the text. Isopachs (in excess of 500m) for Waulsortian facies identify the two main depocentres (Shannon Trough and Dublin Basin). Adapted from Hitzman (1995a), and Lees & Miller (1995).

temporaneous fauna was clearly swept into fractures opened up at the top of a mound from adjacent environments and pre-dates the blanket of siliciclastic mud which finally buried the Waulsortian mud-mound complexes in the Dublin Basin.

Apart from crinoids, the dominant biota in the Waulsortian mounds is fenestellid bryozoans, which occur either as elongate fronds or as bioclastic hash. In addition, sponge spicules can be also locally common, as well as ostracods. Plurilocular foraminifers are generally sparse and calcareous algae are virtually absent, except for rare occurrences of dasyclads (e.g. *Koninckopora*) in the upper part of mounds in the Dublin Basin (Jones *et al.* 1988; Somerville *et al.* 1992; Lees & Miller, 1995).

Deeper-water Waulsortian-type mud-mounds continued into the Viséan with a similar dominance of crinoids, fenestellid bryozoans and sponge spicules. However, changes in the microfossil diversity is evident, with the appearance of archaediscid foraminifers, dasycladacean algae and *in situ* colonial rugose corals (*Siphonodendron*) recorded near the top of larger mounds in the Asbian and Brigantian (Table 1). Nevertheless, corals were not sufficiently abundant in Waulsortian mounds to form a true framework like in modern coral reefs.

Depositional setting and water depth

Waulsortian mud-bank complexes in the Tournaisian developed in deep water (water depths between 150m to 300m) on the distal parts of ramps (Table 1) in a belt extending from the Waulsort region of Belgium (type section for these mounds) westwards to southern Ireland (Lees & Miller, 1995) and northwards into the Dublin Basin (Jones *et al.* 1988; Somerville *et al.* 1992). Four depth-related phases (A-D) were distinguished in these Waulsortian mud-mounds in Ireland (Lees & Miller 1995), with only the components present in Phase D (the highest/youngest phase) suggesting that the mounds built up from the aphotic zone into shallower-water dysphotic to euphotic levels (less than 100m water depth) which permitted the colonization of the mound by light-requiring dasycladacean algae. Components of Phases C and D are commonly recognized in the Waulsortian mounds in the Dublin Basin (Jones *et al.* 1988; Somerville *et al.* 1992), but elsewhere in the southern Irish Midlands the components of the deeper water aphotic phases A and B predominate in a region where the effects of the marine trangression which advanced northwards across Ireland from the south were first experienced (Table 1).

(B) Mineralization

Lower Carboniferous rocks host all of the major base metal (Zn-Pb) and barite deposits in Ireland (Table 1). The largest ore body in Ireland at Navan occurs in the oldest Courceyan carbonate lithologies but most other ore deposits are developed at a higher stratigraphic level in the Waulsortian limestones.

Geological Setting of Navan Orebody

The Navan orebody (70Mt, grading 12% combined Zn and Pb) is hosted in Courceyan-aged Navan Group rocks (shallow marine sandy bioclastic limestones, oolites and micrites) and is Europe's largest Zn-Pb deposit (World's fifth largest Zn deposit). It is more than three times larger than the largest known Waulsortian-hosted deposit at Lisheen (21Mt).

Sulphides occur in stratabound lenses with high grade mineralization in mainly undolomitized micrites and grainstones beneath sandy or shaly dolomite horizons, suggesting that these units facilitated the lateral flow of ascending hydrothermal fluids and provided sites for ore deposition (Hitzman 1995b; Anderson *et al.* 1998). This stratabound mineralization is truncated by a submarine erosion surface overlain by a late Chadian-Arundian olistostrome. However, mineralization extends above the erosion surface into the boulder conglomerate orebody. It was once considered that most of the mineralization was pre-unconformity (i.e. pre-Arundian) in age but it is now realized that much of the ore deposition was post-Arundian in age (Peace & Wallace 1999).

The Navan deposit occurs between several ENE-trending normal faults and metal distribution patterns are controlled by fracturing related to these faults, although the faults themselves do not contain sulphides (Anderson *et al.* 1998). The sulphides extend up to 200m away from faults and fractures. Some faults are cut by the unconformity but others cut across the erosion surface and sulphide bodies occur in the Boulder conglomerate olistostrome above the unconformity (Hitzman 1995b).

Geological Setting of Lisheen and Galmoy deposits

Mineralization in both deposits occurred primarily at or near the base of the dolomitized and locally brecciated Waulsortian mud-mound facies (as also developed in the former deposits at Silvermines and Tynagh) and above the argillaceous bioclastic limestone (ABL) facies (Figure 1). Sulphides are also present in significant amount below the Waulsortian in oolitic members (e.g. Lisduff Oolite at Lisheen and Galmoy, and Lower Dolomite at Silvermines).

Structural control is evident at both of these deposits. The major E-W trending Killoran and Derryville fault zones at Lisheen control the thickest portions of the orebodies and N-S hanging wall faults control the distribution grade. Individual sulphide lenses extend up to 200m from the faults although they can amalgamate into a stratiform lens up to 600m from the main fault zone (Shearley *et al.* 1996; Hitzman 1995b). At Galmoy the two main orebodies are controlled by proximity to ENE-trending faults.

The Irish Base Metal Deposits

The base metal ore deposits of the Irish Midlands have been classified variously as either Mississippi Valley-type (MVT) or as sedimentary-exhalative (sedex) deposits. However, most recent work suggests that the Irish deposits are epigenetic and therefore are more closely related to the MVT class of deposits (e.g. Hitzman 1995b; Peace & Wallace 1999). They have been referred to as 'Irish-MVT' deposits, but perhaps they are best now regarded as 'Irish type' deposits to recognize their distinction from MVT deposits. The Irish deposits are characterized by: (i) a dominance of sphalerite over galena; (ii) fluid inclusion studies indicate that some Irish deposits formed at relatively higher temperatures (~150°C to 300°C) than many MVT deposits (~70°C to 150°C); (iii) the Irish deposits are in tectonically more complex settings; (iv) normal faults exert considerably more control on mineralization than in many MVT deposits.

Two separate models concerning the origin of sulphide mineralization and associated epigenetic carbonates have been proposed: 1) gravity driven fluid flow model (Hitzman 1995b). Here basinal fluids were driven, by gravity or compaction, out of the South Munster Basin and flowed northward through the underlying Old Red Sandstone. Upon reaching the Irish Midlands the fluids ascended along faults into overlying Lower Carboniferous car-

Age (Ma)		SER.	STAGE	Facies	Depositional setting	Tectonism & volcanic episodes (V)	Palaeoclimate	Economic minerals
290	CARBONIFEROUS	WESTPH.		Sandstones, shales coal seams	Deltas	Variscan Orogeny	Equatorial humid	Anthracite (Kilkenny)
312		NAMUR.		Shales, sandstones	Deep-water basin	Quiescence	Equatorial humid	
325		VISEAN (Late)	BRIG.	Mud-mounds & bioherms Bioclastic limestones	Platform/basin margin	V V V V	Tropical-humid	Gypsum (Glangevlin)
			ASB.	Gypsum, Anhydrite	Sabkha	Tectonic pulse (late Asbian-Brigantian)	Tropical-semiarid (seasonal drying)	
			HOLK.	Shales, lst. turbidites, calcisiltites	Deep-water basin		Tropical-humid	
		(Early)	ARUND.	Bioclastic limestones	Shallow-water Platform and shelves	Quiescence		
				Basalt lavas and tuffs		V V	Tropical-semiarid (seasonal wetting)	
342		TOURNAISIAN	CHAD.	Waulsortian mud-mounds	Deep-water ramps	Tectonic pulse (late Courceyan-Chadian)	Tropical-semiarid (seasonal wetting)	**Zn, Pb (Lisheen)** Ba (Ballynoe) **Zn, Pb (Navan)**
			COUR.	Limestones and shales, ssts, bioturbation	Shallow-water ramps and shelves			
354	DEVONIAN			Red ssts., conglom, siltstones palaeosols (calcretes) -'Red-beds'	Continental fluvial, alluvial, coastal plain	Quiescence	Tropical-semiarid	Cu, Fe

Table 1. Generalised summary of depositional, tectonic and climatic events in the Carboniferous of Ireland

bonate rocks where sulphide mineralization and dolomitization occurred. In such a model metals are derived from basinal sedimentary rocks with which fluids interacted (Hitzman 1995b).

2) convection model (Russell 1986). In this model cool seawater descended along extensional faults into Lower Palaeozoic igneous and metamorphic basement rock where it was heated and leached metals from the country rock. The heated, mineralized fluid then rose buoyantly along faults. Near the seafloor this fluid mixed with seawater and/or pore fluids and precipitated sulphide ore bodies in overlying Carboniferous limestones. The first of these hypotheses requires a basin-scale hydrological system with a large horizontal flow component; the second hypothesis requires localized convection-driven systems with a primarily vertical flow component (see Hitzman 1995b).

Dolomitization and mineralization

Regional dolomitization has affected much of the Lower Carboniferous limestones in the southern Irish Midlands north of Cork. In this area, dolomite has largely replaced limestones from the base of the Carboniferous up through the Waulsortian and into overlying supra-Waulsortian shelf limestones as young as Asbian in age (c. 330Ma; Table 1) (Wright *et al.* 1999, 2001; Gregg *et al.* 2001). Large scale replacement dolomitization of Carboniferous limestones also is associated with faulting in the Irish base metal deposits, including Navan (Braithwaite & Rizzi, 1997) and at Silvermines (Hitzman 1995b). At Lisheen and Galmoy in the Rathdowney Trend (Figure 1) mineralizing fluids emanating from the controlling faults altered pre-existing regional dolomite producing what are interpreted to be a variety of recrystallization textures (Hitzman 1995b; Shearley *et al.* 1996).

Epigenetic open-space-filling dolomite cement has been recognized at all of the Irish ore deposits (Hitzman 1995b; Shearley *et al.* 1996; Braithwaite & Rizzi 1997; Gregg *et al.* 2001). Two main types of regional dolomite have been recognized (Gregg *et al*. 2001): (i) finely crystalline (0.01 to 0.3mm) planar replacive dolomite that is dominantly nonferroan, followed commonly by (ii) coarse (≥0.5mm) nonplanar replacive dolomite, and pervasive void-filling saddle dolomite cement which is associated frequently with Zn-Pb mineralization. The petrography and geochemistry of planar dolomites are consistent with an early diagenetic origin, possibly in equilibrium with modified Carboniferous seawater. Where the Waulsortian and other limestones were exposed to hydrothermal fluids (70° to 280°C), planar dolomite underwent a neomorphic recrystallization to a coarser crystalline, planar and nonplanar dolomite. This history of multiple stages of dolomitization is significantly more complex than earlier models proposed for the Irish Midlands. The later coarser dolomite partially to completely fills all available porosity, especially vugs, fractures, and breccias. The ore-related dolomite cements are known to have distinctive compositional zoning, visible using cathodoluminescence (CL) petrography.

Cathodoluminescence (CL)

Based on examination of over 860 core and outcrop samples in the Waulsortian, sub-Waulsortian and supra-Waulsortian, a subset of 270 samples was selected for CL analysis. The results of this investigation have permitted the identification of a CL microstratigraphy in open-space-filling, epigenetic dolomite throughout the Irish Midlands and Dublin Basin. This CL stratigraphy is characterized by 4 distinct cement zones (Wright *et al.* 1999, Gregg *et al.* 2001) followed usually by calcite which occasionally is accompanied by hydrocarbons (bitumen). These zones include: (1) a mottled, bright red inner zone; (2) alternating dull and bright red CL bands; (3) alternating dull red and non-CL bands or entirely non-CL band; (4) a bright red CL zone. These zones all predate the sulphides.

Geochemical parameters

(i) Fluid inclusions

Fluid inclusion microthermometry of host carbonates, epigenetic dolomite and sphalerite has been used to characterize the potential mineralizing fluids. Over 160 fluid inclusions from the same suite of samples as for the above CL study have been analysed (Gregg *et al.* 2001). The distribution of fluid inclusion homogenization temperatures (Th) and final melting temperatures (Tm) indicate two, possibly three, distinct fluids that are present in the Irish Midlands. Type 1 fluid is characterized by low temperatures (Th = 70° to 120°C) and high salinities (Tm = –15° to –40°C). Type 2 and Type 3 fluids are characterized by moderate to high temperatures (Th = 99° to 300°C) and low salinities (Tm = 0° to –13°C). Types 2 and 3 fluids may represent end members of a cooling trend in relatively dilute fluids that precipitated dolomite. The type 1 fluid is distinct from the other two fluid types in that it represents introduction of a saline fluid at relatively low temperature. The presence of multiple chemically and thermally distinct fluids reveals even more complexity during the late diagenetic history of dolomitization.

(ii) Stable isotopes

Replacement dolomites and carbonate cements have been analyzed regionally for their carbon, oxygen and strontium isotope compositions. Also, individual CL zones have been analyzed to determine if geochemically related fluids were responsible for the diagenesis of host rock and precipitation of cements at different localities. The results of this study (Wright *et al.* 2000) have established that planar dolomite has average $\delta^{18}O$ and $\delta^{13}C$ values (‰ PDB) of –4.8 and 3.9, respectively. These are lower oxygen and slightly higher carbon isotope values than averages for marine limestones in the Waulsortian ($\delta^{18}O$ = –2.2, $\delta^{13}C$ = 3.7) (Gregg *et al.* 2001). Mean C and O isotope values of planar replacive dolomite are also distinct from those of nonplanar and saddle dolomite cement (–7.0 and 3.3; –7.4 and 2.4, respectively) (Wright *et al.* in press). Interpretation of the stable isotope data like that for fluid inclusions indicates a complex history involving several distinct fluids during dolomite cementation (Wright *et al.* 1999).

Modellers are now expanding the capability of reactive flow hydrogeologic-geochemical models to simulate groundwater chemistry, patterns of rock alteration, and ore mineralization in fractured rock (Wright *et al.* 2000). Future studies in geochemical research are likely to focus on chemical interactions of basinal/basement fluids along stratigraphic and faulted pathways and will provide a basis for constraining theoretical models of deep groundwater flow and mass transport that are being developed for the Irish Midlands.

References

Anderson I K, Ashton J H, Boyce A J, Fallick A E & Russell M J, 1998, Ore depositional processes in the Navan Zn-Pb deposit, Ireland. *Economic Geology* **93**, 535-563.

Braithwaite C J R & Rizzi G, 1997, The geometry and petrogenesis of hydrothermal dolomites at Navan, Ireland. *Sedimentology*, **44,** 421-440.

Gregg J M, Johnson A W, Shelton K L, Somerville I D & Wright W, 2001, Dolomitization of the Waulsortian Limestone (Lower Carboniferous) Irish Midlands. *Sedimentology* **48,** 745-766.

Hitzman M, 1995a, Geological setting of the Irish Zn-Pb- (Ba-Ag) orefield. In: Anderson K, Ashton J, Earls G, Hitzman M & Tear S (eds), *Irish Carbonate-hosted Zn-Pb Deposits: Society of Economic Geologists and Irish Association of Economic geologists, Field Conference 13-19 May 1995*, GuideBook Series **21**, 3-23.

Hitzman M, 1995b, Mineralization in the Irish Zn-Pb- (Ba-Ag) orefield. In: Anderson K, Ashton J, Earls G, Hitzman M & Tear S (eds), *Irish Carbonate-hosted Zn-Pb Deposits: Society of Economic Geologists and Irish Association of Economic geologists, Field Conference 13-19 May 1995*, GuideBook Series **21**, 3-23.

Jones G L L, Somerville I D & Strogen P, 1988, The Lower Carboniferous (Dinantian) of the Swords area: sedimentation and tectonics in the Dublin Basin. *Geological Journal* **23**, 221-248.

Lees A & Miller J, 1995, Waulsortian banks, In: Monty C, Bosence D W J, Bridges P H & Pratt B (eds), *Carbonate Mud-mounds: their Origin and Evolution:* Special Publication, International Association of Sedimentologists, **23**, 191-271.

Peace W M & Wallace M, 1999, Timing of mineralization at the Navan Zn-Pb deposit: A post-Arundian age for the Irish Mineralization. *Geology*, **28**, 711-714.

Russell M J, 1986, Extension and convection: a genetic model for the Irish Carboniferous base metal and barite deposits: In: Andrew C J, Crowe R W A, Finlay S, Pennell W M & Pyne J F(eds), *Geology and genesis of mineral deposits in Ireland,* Irish Association for Economic Geology 545-554.

Shearley E, Redmond P, King M & Goodman R, 1996, Geological controls on mineralization and dolomitization of the Lisheen Zn-Pb-Ag deposit, C. Tipperary, Ireland. In: Strogen P, Somerville I D & Jones G L (eds), *Recent Advances in Lower Carboniferous Geology,* Special Publication Geological Society, **107**, 23-33.

Somerville I D, Strogen P & Jones G Ll, 1992, Mid-Dinantian Waulsortian buildups in the Dublin Basin, Ireland. *Sedimentary Geology,* **79**, 91-116.

Strogen P, Somerville I D, Pickard N A H, Jones G Ll & Fleming M, 1996, Controls on ramp, platform and basinal sedimentation in the Dinantian of the Dublin Basin and Shannon Trough, Ireland. In: Strogen P, Somerville I D & Jones, G Ll (eds), *Recent Advances in Lower Carboniferous Geology*. Geological Society Special Publication, **107**, 263-279.

Wright W, Somerville I D, Gregg J M & Shelton K L, 1999, Dolomite CL and $\delta^{18}O$ & $\delta^{13}C$ data from the Irish Midlands and Dublin Basin, Carboniferous. In: Stanley C J *et al.* (eds) *Mineral Deposits: Processes to Processing.* Proceedings of the Fifth Biennial SGA Meeting and the Tenth Quadrennial IAGOD Symposium, Imperial College London, 22-25th August 1999, 913-916.

Wright W, Johnson A W, Shelton K L, Somerville I D & Gregg J M, 2000, Fluid migration and rock interactions during dolomitisation of the Dinantian in Irish Midlands and Dublin Basin. *Journal of Geochemical Exploration,* **69-70**, 159-164.

Wright W, Somerville I D, Gregg J M, Johnson A W & Shelton K L, Dolomitization and Neomorphism of Irish Lower Carboniferous (Early Mississippian) limestones: evidence from petrographic and isotopic data. *Geological Journal*, **37**, (in press).

Book reviews

Water on Mars by Michael H. Carr, 1996, Oxford University Press, 229pp, £60 (hardback) ISBN 0195099389

Water on Mars was of particular interest for me as I am studying S269 Earth and Life. So, when the opportunity presented itself, I eagerly snapped up the chance to read this book. The author, Michael H. Carr, has put together a comprehensive book on the recent investigations of work done on data obtained by various space missions and meteorites on the planet Mars. I found the book, consisting of 10 chapters, to be one that is best dipped into, rather than reading it cover to cover. Chapter 1, Introduction, gave an excellent historical and geological background on the Red planet. Chapters 2, The Present Water Cycle and Stability Relations; 3, Outflow Channels; 4, Valley Network; and 5, Ground Ice, dealt specifically with the main focus of the book, namely evidence of the presence of water on Mars in the past and in the present. In general, I found the text to be technical, yet in most cases within my ability to comprehend. At times some of the mathematical formulae were complex. However, the author consistently, comprehensively and objectively presented several viewpoints to explain specific phenomena evidenced on the photographs transmitted back from various space missions. These photographs (b/w) provided excellent examples to back up claims. Explanations negating some theories or suppositions helped me to see how difficult and controversial this research can be.

Chapter 6, Climate Change, and Chapter 7, Accretion and Evolution of Water discussed the theories behind how and why water was and is on Mars. Chapter 8, Implications for Life, examines the research being done to determine if and where life might have evolved on Mars. Chapter 9, Future Mars Exploration, focussed on unmanned and human missions being considered worldwide. Budgetary constraints, political environments and our innate human curiosity were presented. The pros and cons of various missions demonstrated the need for careful planning to ensure successful scientific research. Finally, Chapter 10, Summary and Conclusions, wrapped everything up quite neatly.

Besides the fantastic pictures and the author's thoroughness in presenting all sides of the complex story, I discovered that detailed planetary geology was actually possible without direct exploration. I was in awe to learn that people could look at satellite photographs and determine the erosion rate, propose mechanisms for valley formation, and explain processes for the resulting terrain, etc. The jury is still out on whether there is or was life on Mars. However, Michael Carr puts forth a very strong case to show that water was and could continue to be an important factor in the evolution of the planet. As we move closer to human exploration of the Red Planet, the previous research should enable us to explore specific Martian terrain that will further advance the various scientific endeavours. As with much research, more questions appear as each previous question is answered. I look forward to keeping tabs on how this area of study proceeds.

Diane M. Culpin BA (Hons), USA, Continuing ES student

Travels with the Fossil hunters, by Peter J Whybrow (ed) of the Natural History Museum, 2000, Cambridge University Press, 212 pages, £19.95 (hardback) ISBN 0521663016.

This is a beautiful book. At first glance it looks like a rather glossy coffee table book, but when you stop looking at the numerous spectacular colour photographs and start to read the fascinating accounts of twelve British palaeontologists working in remote areas of the globe, you realise that it is much more than that! The accounts of the hardships and vicissitudes endured by field geologists in the frozen wastes of Antarctica and Tibet or the deserts of Arabia and Africa are truly fascinating. I shan't complain again about a rainy day in Wales or no en-suite in Scotland. The chapter headings of quotations from earlier visitors to these areas form intriguing links with the past. Armchair travellers will delight in the glimpses of other cultures and far flung places. As for me, I couldn't decide whether I wanted to go "Digging for Dragons in China" or "Across Tibet by jeep, pony and foot", but get it from your library or ask for it for Christmas and decide for yourself.

Mary Howie BA Hons (Open) & Hon. Curatorial Associate at The Manchester Museum

Bending, Shaking and Electrifying the Celtic Crust

Dr Colin Brown, Applied Geophysics Unit, National University of Ireland, Galway, Ireland

The logic that we use for research in Earth Science is quite different from the logic that we use in conventional laboratory-based sciences such as Physics or Chemistry. I will try to illustrate this by summarising some of the geophysical interpretations that allow us to infer the physical properties of the Irish crust.

In the Chemistry or Physics laboratory, the starting point is a controlling state-of-affairs in an experiment whose outcome (a resulting state-of-affairs) can be observed. Causal laws can be used to describe this process. A change in the controlling state-of-affairs will give rise to a resulting state-of-affairs. The appropriate causal laws can predict this using deductive inference illustrated below as:

If p, then q; p is given; q must be the case.

When the controlling state-of-affairs and the resulting state-of-affairs are known, a process of inductive inference can be used to refine or find new causal laws that unite the two states-of-affairs. This is often achieved by systematisation and generalisation (simplification) of the data. The inference makes the laws probable but not necessarily true.

This is different from what happens in Earth Science where we start with a resulting state-of-affairs based on observations on or just beneath the Earth's surface. Then we apply developmental laws to retrodict states of affairs in the geological past. The hypothesised controlling state-of-affairs is inferred using abductive logic, illustrated below as:

If p, then q; q is given; p may be the case.

Developmental laws in Earth Science relate to systems that are so complex that it is extremely difficult to base them upon general laws of nature and they are often just one step away from inductive generalisations. In Earth Science one should only accept explanations for the geological conditions in the past with the proviso that later revisions may be needed, as any actual state-of-affairs may result from various causes or various laws. The implication is that the following story about the tectonic processes that have given rise to present-day physical properties of the Irish crust is incomplete.

Geology of Ireland

A simple view of the geology of the Irish crust is shown in Figure 1. The major surface geological observations have been explained by invoking theories concerning the collision of the Laurentian and Avalonian continents during the Caledonian Orogeny and the subsequent deformation during the Variscan Orogeny. The convergence of the two continents in the Caledonian closed the Iapetus Ocean leaving Laurentia roughly north of a map line from Dublin to Limerick and Avalonia to its south. The convergence was accompanied in its final stages by major strike-slip motions of independent terranes (Figure 1) assembled into linear NE – SW zones. Some of these terranes have boundaries that coincide with major faults exhibiting abundant field evidence for sinistral strike-slip movement. The Irish Midlands was probably uplifted after the final assemblage of these terranes in the Silurian. The crust was then stretched and during the Devonian, the Munster Basin accumulated a thick succession of sandstone deposits while the Irish Midlands was being eroded. In the early Carboniferous the stretching became most obvious in the Irish Midlands where sandstone and, subsequently, limestone were deposited. In the late Carboniferous, the crust was compressed during the Variscan Orogeny. Most of this shortening was restricted to a map line south of Dingle to Dungarvan, especially in the vicinity of Killarney and Mallow where there is evidence at the surface for major Variscan thrust faults (Killarney-Mallow Fault Zone).

The relevant geology of the individual terranes can be summarised as follows. Below about 1500m of Carboniferous limestone, the Grampian Terrane has continental basement similar to the granulite-facies rocks of the Ox Mountains. The Northwestern Terrane consists of about 1000m of upper Palaeozoic sandstone and limestone resting unconformably on Precambrian basement. It has no counterpart in Scotland. The Midland Valley Terrane has about 1000m of limestone resting unconformably on an unknown thickness of Devonian sandstone. These sediments cover Ordovician island-arc volcanic and probably Precambrian granulite-facies rocks of the Laurentian foreland. Beneath the Carboniferous limestone of the Central Terrane is a complex of oceanic trench deposits accreted along the Laurentian margin. These are characterised by Ordovician black shales, greywackes, cherts and pillow lavas. Some xenoliths suggest that Laurentian crustal rocks were present beneath this terrane during the Carboniferous. The boundary between the Central and Leinster Terrane is called the Iapetus Suture Zone. Pre-Silurian rocks of Avalonia underlie the Leinster Terrane. They include Ordovician-Silurian shales, basic to andesitic volcanics, limestone and greywacke sandstone. The Ordovician volcanic sequences are typical of a continental margin formed by southward subduction of oceanic crust beneath Avalonia, and the Leinster granite may represent the final suturing of the Laurentian and Avalonian plates in the late-Silurian. In the southwest, the Munster Basin consists of thick sequences of non-marine red-bed sandstone and shales with a number of synclinal cores of marine facies sediments.

Some of these ideas about the tectonic processes that have shaped Ireland can be tested and refined using geophysical data that allow us to infer the distribution of physical properties of rock types at depths beyond the scope of conventional geological mapping techniques.

Magnetic properties of the crust

The presence of magnetic minerals (predominantly magnetite) in rocks within the crust causes the magnetic field to vary over the Earth's surface. The Geological Survey of Ireland and Geological Survey of Northern Ireland have measured the magnetic field over Ireland using a magnetometer on an aeroplane flying backwards and forwards along lines typically spaced by about 1000m and orientated in a NW-SE direction. The magnetic field can be used to infer the magnetic properties of the rocks that make up the Irish crust and the patterns can be used to guess at the tectonic processes that emplaced these magnetic rocks. An example taken from a NUI, Galway PhD thesis by Dr. Gareth Armstrong (Armstrong 1997) is shown in Figure 2. These magnetic anom-

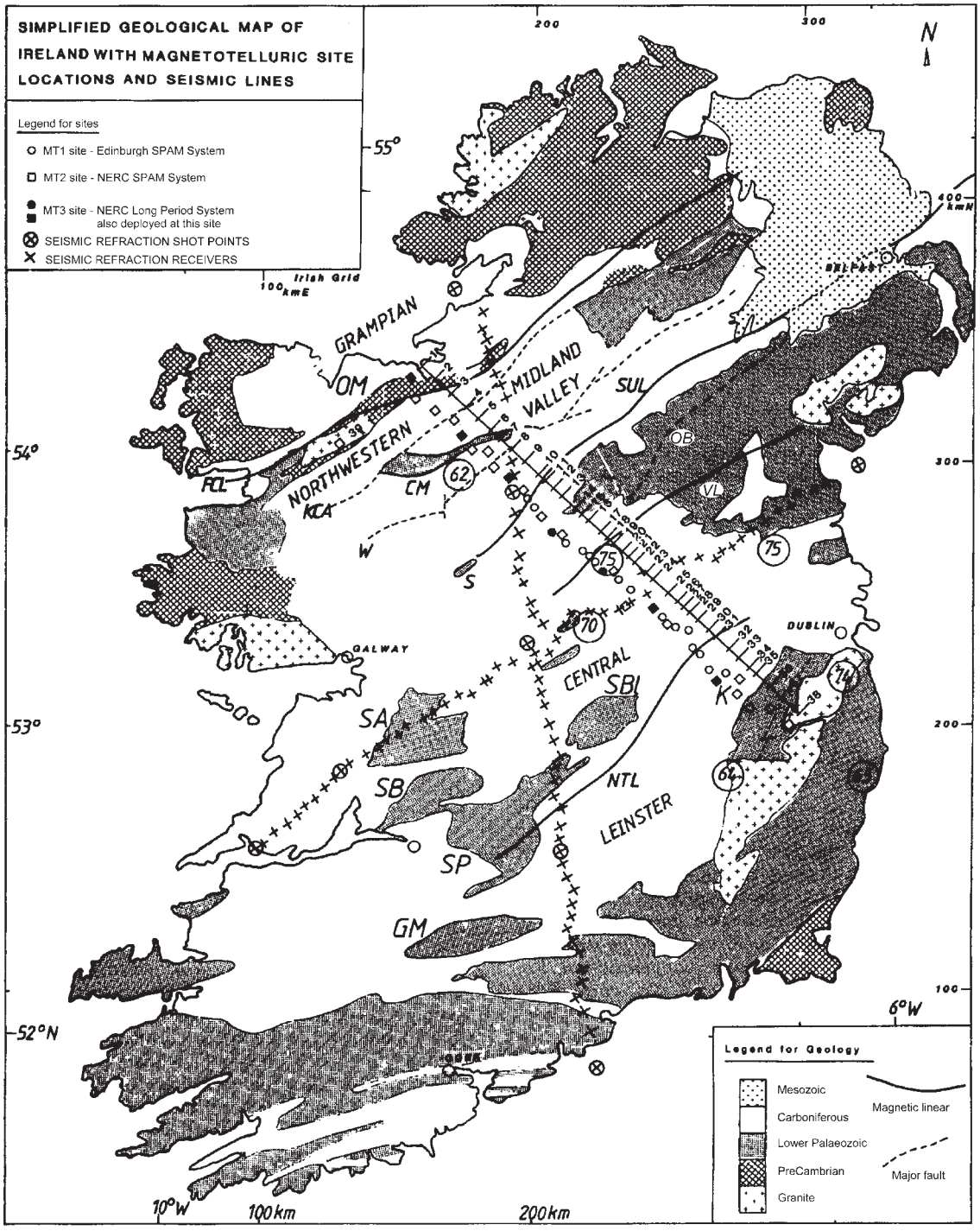

Figure 1. Simplified geological map of Ireland showing the locations of the 38 magnetotelluric sites along the Irish Magnetotelluric Profile. The Caledonian Onshore-Offshore Lithospheric Experiment (COOLE) and Irish Caledonian Suture Seismic Project (ICSSP) seismic refraction lines are orientated approximately N-S and NE-SW respectively. Heat flow values (encircled values in mWm^{-2}) are shown in the vicinity of the Irish Magnetotelluric Profile. OM, Ox Mountains; FCL, Fair Head-Clew Bay Lineament; KCA, Killavil-Castle Archdale Fault; CM, Curlew Mountains; W, Woodbrook Fault; SUL, Southern Uplands Lineament; S, Strokestown Inlier; OB, Orlock Bridge Fault; VL, Virginia Lineament; SA, Slieve Aughty; SB, Slieve Bernagh; SBl, Slieve Bloom; SP, Slieve Phelim; NTL, Navan-Tipperary Lineament; GM, Galtee Mountains; K, Kildare Inlier.

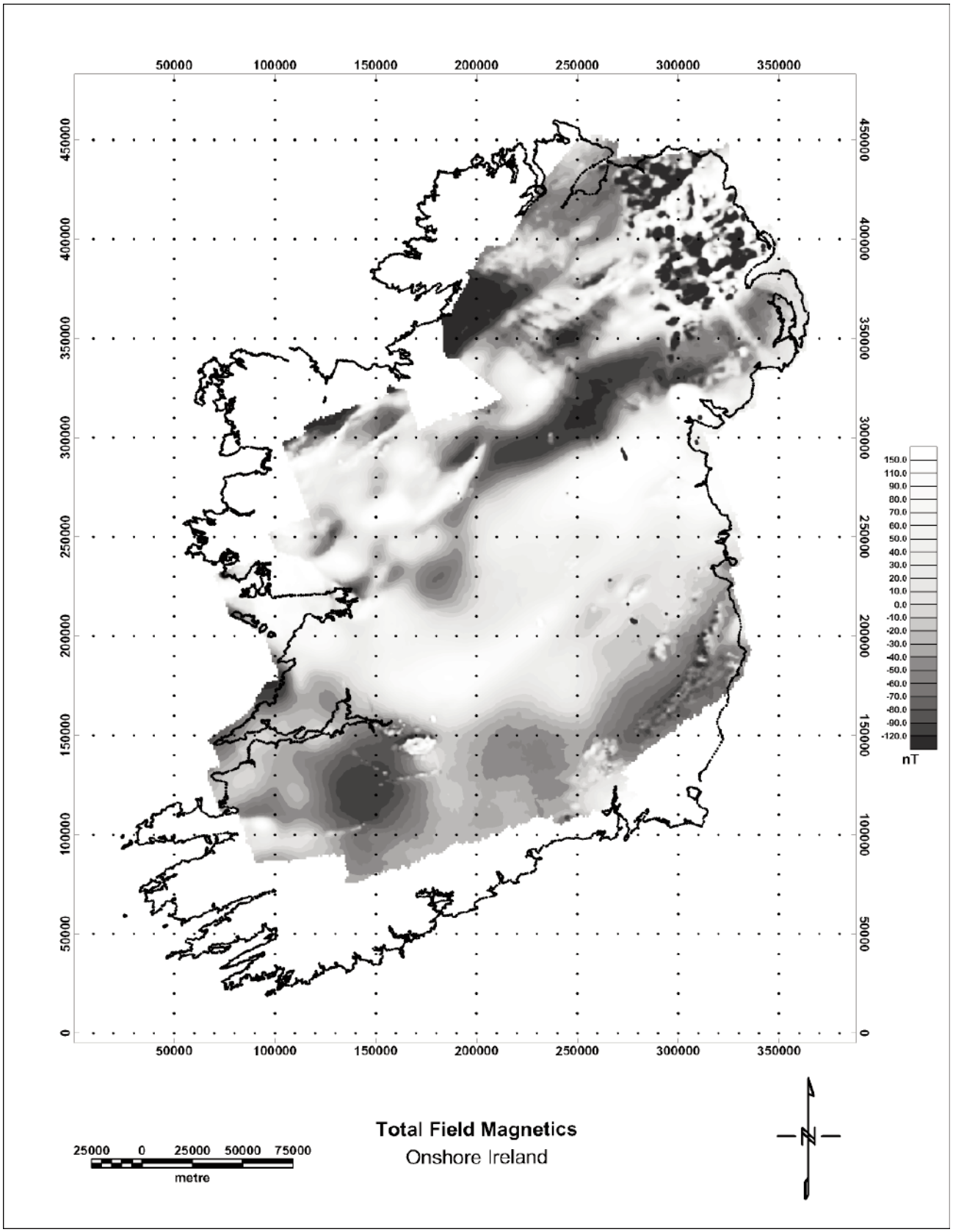

Figure 2. Total field aeromagnetic map for onshore Ireland. The data have been collected by the Geological Survey of Ireland and the Geological Survey of Northern Ireland and have been processed by Dr. Gareth Armstrong at NUI, Galway. Dark colours are negative magnetic anomalies (minimum of –120nT) and light colours are positive anomalies (maximum of +120nT).

alies tell us about the strength and disposition of magnetic rocks within the crust. In the Central Terrane there is a broad magnetic anomaly high (light colour) which, in the northeast, is separated from a broad magnetic anomaly low (dark shade) by the Virginia Lineament (VL in Figure 1). The proximity of a high and low magnetic anomaly like this is what one would expect from a single magnetised body. The rocks at the surface, however, are insufficiently magnetised to provide such strong anomalies so its source must have a top surface at some depth. The magnetic anomaly high extends towards the Shannon Estuary and this suggests that the source could be associated with buried magnetic rocks of the accretionary complex deposits in the Iapetus Suture Zone. There is also evidence in this map of (dark, negative) magnetic lineaments that are orientated in a NE-SW direction (e.g. Sligo Bay to Clew Bay), NW-SE (e.g. Sligo Bay to Dublin) and (light, positive) circular anomalies (e.g. east of the Shannon Estuary). Their coincidence with faults, dykes and exposed volcanic rocks means that the top surface of their magnetic source is close to the Earth's surface.

We can filter these data using techniques involving Fourier analysis. This can emphasise the magnetic characteristics of near-surface features and remove the magnetic effects of rocks whose top surfaces are at great depths within the crust. These techniques clearly identify the presence of volcanic rocks, for example, in the Tertiary Igneous Province of Northern Ireland and in the vicinity of Limerick. They also show the coincidence of some magnetic lineaments with some of the major faults (Killavil-Castle Archdale = KCA, Fair Head = Clew Bay Lineament = FCL) in Figure 1. Whilst some magnetic minerals in the fault gouge may be responsible for these lineaments, their amplitudes imply that their sources extend from near the surface to substantial depths within the crust. The Fourier techniques help to clarify the location of the terrane boundaries summarised in Figure 1, but it is difficult to make unambiguous statements about the depth of the magnetic sources responsible for these features. We are fortunate in Ireland that the rocks responsible for these magnetic anomalies have another physical property that can be imaged using the magnetotelluric technique.

Electrical resistivity properties of the crust

The conduction of electrical currents in rocks is predominantly via interconnected pathways of minor constituents (e.g. fluids and/or very conducting minerals such as graphite and/or Fe-Ti oxides and sulphides) and to a lesser extent via solid electrolytic conduction through the rock matrix. If the rock is a poor conductor of electric current, it has a high electrical resistivity (typically > 1000Ωm) whereas a good conductor will have a low resistivity (typically < 100Ωm). After we estimate the resistivity distribution at depth within the crust, we can infer the type of rocks and retrodict some of the geological processes responsible for that distribution.

There are several ways of inferring the resistivity distribution. One example is the direct-current electrical resistivity method used for near-surface investigations for groundwater resources or leachate from waste sites. However, the magnetotelluric technique is the only practical way to investigate the resistivity at depths of several tens of kilometres. A single–site magnetotelluric sounding consists of the simultaneous recording of time variations of natural electric and magnetic fields. These fields originate from the ionosphere, some 100km above the Earth's surface,

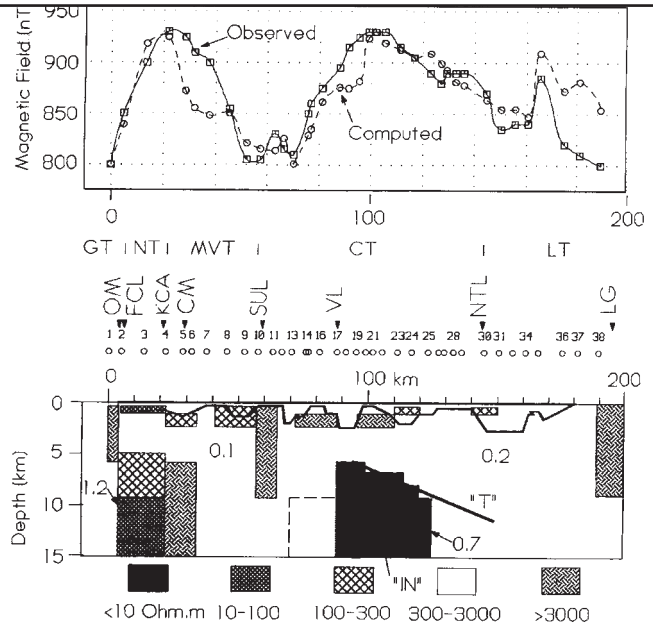

Figure 3. Interpretation of the resistivity and magnetic properties in the upper crust along the Irish Magnetotelluric Profile (after Brown & Whelan 1995). GT, Grampian Terrane; NT, Northern Terrane; MVT, Midland Valley Terrane; CT, Central Terrane; LT, Leinster Terrane. Other abbreviations are described in Figure 1. The low resistivity zones beneath sites 2 & 3 and beneath sites 17 – 25 are also responsible for the positive magnetic anomalies seen in the upper part of the diagram.

or from continual lightning storms in equatorial regions that propagate primary electric and magnetic fields around the Earth. When these fields are incident on the Earth's surface they generate electric currents within the Earth by a process known as electromagnetic induction. The currents generate secondary fields that diffuse back to the Earth's surface and the magnetotelluric sounding measures the sum of the primary and secondary electric and magnetic fields. The high frequency fields tell us about the electrical resistivity variations within the top 1000m whereas the low frequency fields can tell us about the resistivity in the lower crust and mantle.

Figure 3 shows a cross-section of the resistivity distribution along the Irish Magnetotelluric Profile (IMP) from Sligo Bay to Wicklow (Figure 1). There are 2 good conductors at depths greater than 5km beneath the Northern and Central Terranes. These are roughly coincident with high magnetic anomalies shown in the upper part of the diagram. There are 2 hypotheses that could explain the coincidence of conductive and magnetised rocks at these depths within the crust. Low temperature hydrothermal alteration (serpentinisation) of olivines can produce magnetite with a magnetisation of ~1Am^{-1} and resistivity <100Ωm. This is compatible with geological models that suggest the presence of remnant island arcs buried during the final closure of the Iapetus Ocean. The preferred explanation is based upon evidence from suture zones worldwide that dipping conductive slabs are probably due to metamorphosed graphitic shales within metasedimentary basins. The dipping conductor beneath the Central Terrane could therefore be due to a metasedimentary basin thrust beneath Avalonian crystalline basement. The

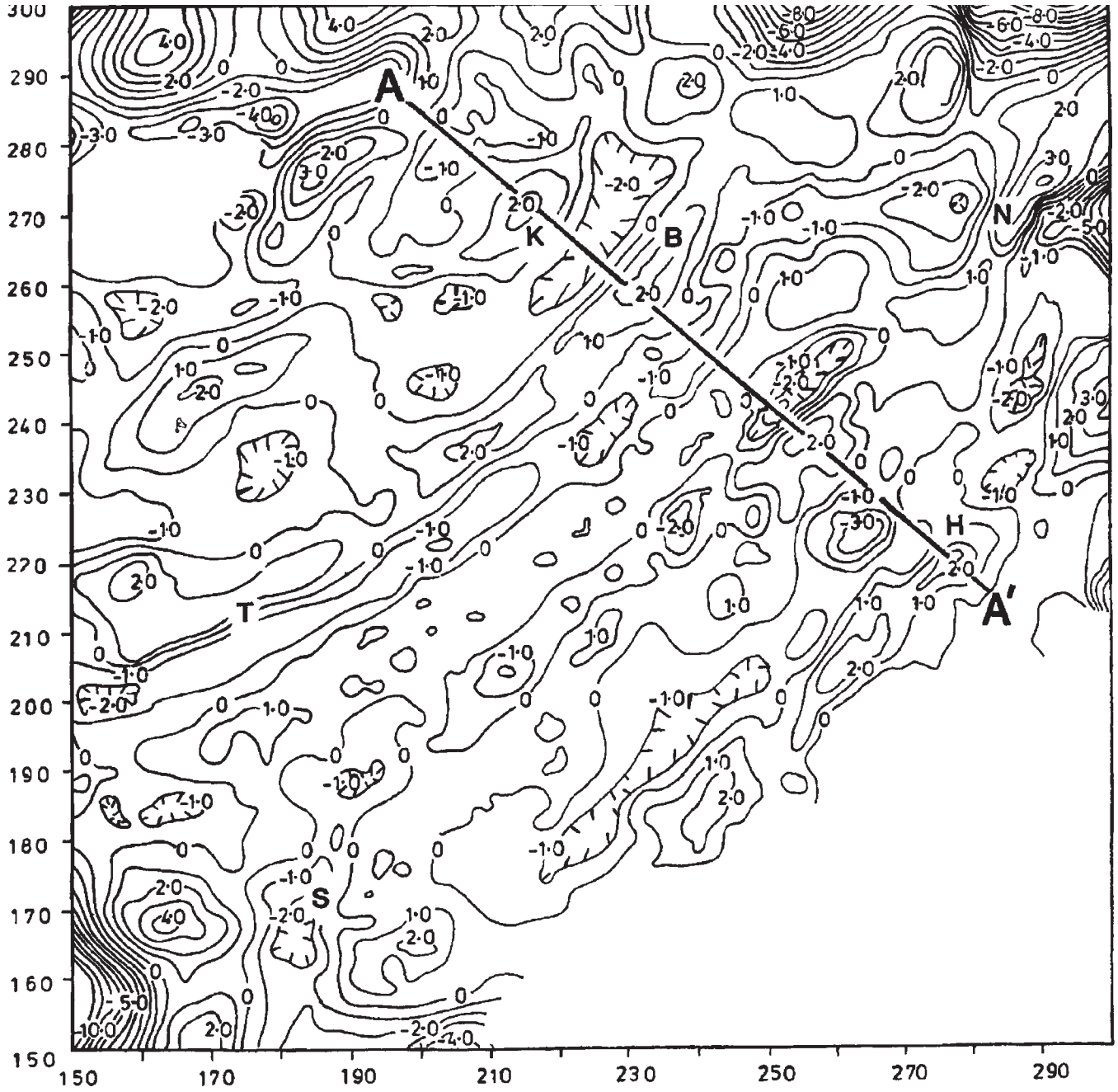

Figure 4. Filtered gravity anomaly map of the Irish Midlands emphasising near-surface block-trough structures (after Brown & Williams 1985). The gravity anomalies are contoured in mGal. The line AA' corresponds roughly to the location of the Irish Magnetotelluric Profile. K, Keel block (centred at ~80km along the crustal section in Figure 3); B, Ballinalack block (centred at ~100km in Figure 3). Co-ordinates are Irish National Grid.

metasediments could also contain metallic minerals, particularly iron that could exist as magnetised pyrrhotite. These metasediments could be the ultimate source of economic mineralisation in the Irish Midlands.

It is worth commenting further on mineralisation in the Irish Midlands by focusing on the upper crustal resistivity section in Figure 3 where we can see 5 resistive (> 300Ωm) blocks near the surface. In the northwest, a resistive block is associated with the Ox Mountains while in the southeast, the resistive block is associated with the Leinster Granite. We cannot be confident of the geometry of their lower boundaries. The other 3 resistive blocks in the Irish Midlands are interpreted to be Ordovician volcanic rocks that were initially pushed up during the convergence of Laurentia and Avalonia. When crustal stretching occurred during the Carboniferous, their thrust faults were reactivated as normal faults so there are Ordovician volcanic cores beneath the Silurian inliers in the Midlands with Carboniferous troughs between them. There is a close correlation between the disposition of the blocks and troughs and the mineralisation that exists in the Midlands.

The magnetotelluric profile has given us a cross-section of resistivity with depth that indicated the presence of a block-trough structure. Is there a data set that allows us to look at the aerial distribution of these blocks and troughs?

Density properties of the crust

Ordovician volcanic rocks tend to be dense (~2750kgm^{-3}) and

Carboniferous sediments have densities ~2670kgm^{-3}. Therefore the block-trough structures should be visible in the gravity data because these indicate the density distribution beneath the Earth's surface. Figure 4 shows gravity data over the Irish Midlands collected by the Dublin Institute for Advanced Studies and presented in a paper by Brown & Williams (1985). These data have been filtered using Fourier techniques to emphasise the near-surface (<3km depth) structure. (A more recent paper by O'Reilly *et al*. (1999) illustrates some of these filtering techniques in colour). Figure 4 highlights the block-trough structure identified in the resistivity section (Figure 3). There are positive gravity anomalies over Ordovician blocks (e.g. Keel and Ballinalack blocks) separating negative gravity anomalies over troughs of sediments (and perhaps some smaller buried granites). The gravity data allow us to locate these bodies with different density but they are not particularly good at inferring their depth. Just as we employed the magnetotelluric method to complement the magnetic data, we must use the seismic method to complement the gravity data if we wish to clarify the sub-surface geometry of these structures.

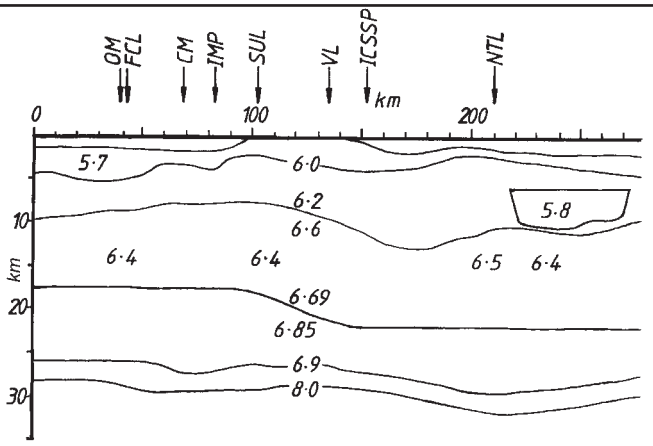

Figure 5. Velocity distribution beneath the COOLE seismic line (after Lowe & Jacob 1989). P-wave velocities in kms^{-1}, depths and distances in km. IMP, Irish Magnetotelluric Profile; ICSSP, Irish Caledonian Suture Seismic Project. Other abbreviations are described in Figure 1.

Seismic velocity properties of the crust

The seismic refraction data from the COOLE line (Lowe & Jacob 1989) gives information on the crust and upper mantle. An explosion is detonated at a known location (shot points in Sligo Bay and off the south coast, see Figure 1) and seismic waves travel through the Earth. We measure how long they take to arrive at different receivers at known locations. From this the variation in the velocity at which seismic waves travel through sub-surface rocks can be estimated (Figure 5). The velocity of the seismic waves in the rocks can be compared with experiments in the laboratory on particular rock types. For example, it is found that P-wave velocities of about 5.6 to 5.7 kms^{-1} imply that the rocks are limestone and sandstone; velocities of about 6.0 to 6.2kms^{-1} are associated with Precambrian crystalline basement; velocities of 6.2 to 6.69kms^{-1} suggest that the rocks are amphibolite-facies felsic gneisses or greenschist-facies gabbros and velocities about 6.85kms^{-1} indicate the presence of mafic granulites.

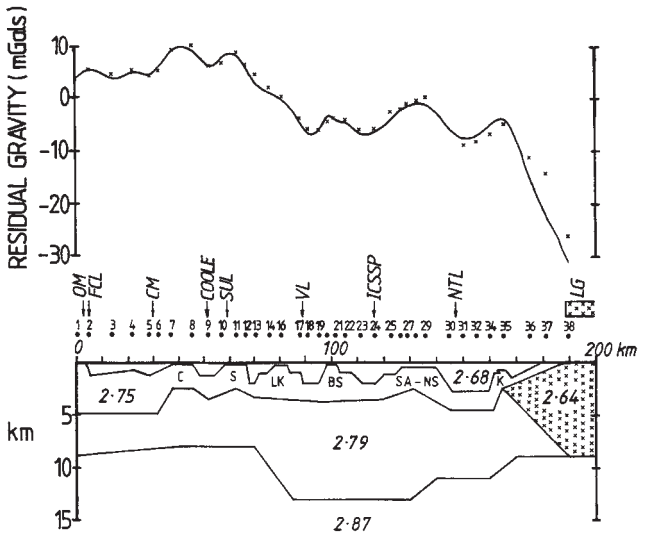

Figure 6. Density distribution beneath the Irish Midlands (after Brown & Whelan 1995). Densities in Mgm^{-3}. S, Strokesdtown block; LK, Longford-Keel block; BS, Ballinalack/Slieve Aughty block; SA-NS, Sion Hill/Arra Mountains – Navan /Silvermines block.

The velocity of seismic waves through different rock types is a function of the density of those rocks. As the seismic refraction method is very good at resolving velocity differences at depth, we can use these results to constrain models of the density distribution at depth that are consistent with gravity data. Figure 6 is an example. The gravity data constrained in this way allow us to model the structure of the blocks and troughs in the top 3–4km with better precision than any of the other geophysical techniques. These models are now known to be over-simplified but they do summarise some of the gross structure of the uppermost crust in central Ireland.

Recent research

There are some new research directions that are giving us additional information about the crustal structure and composition beneath southern Ireland (Variscan) and the continental margin off the west coast of Ireland.

The VARNET experiment involving Dublin Institute for Advanced Studies, University of Karlsruhe, University College Dublin, GFZ-Potsdam, NUI, Galway and University of Copenhagen has acquired some seismic and magnetotelluric profiles. The location of the major seismic line from Galway Bay to the Old Head of Kinsale is shown in Figure 7 and the seismic velocity structure beneath it is shown in Figure 8. These diagrams from a paper by Landes *et al*. (2000) show some interesting results. The Munster Basin – South Munster Basin has a south-dipping feature associated with the Killarney – Mallow Fault Zone. The model shows that there are no lower crustal variations beneath the KMFZ and this has implications for the tectonic processes that have given rise to this major geological feature. Further north, the middle crust thickens beneath the Shannon Estuary. This is related to the Iapetus Suture Zone but the details are not clear at present.

Figure 9 shows a preliminary 3D model for the resistivity structure just to the east of Dingle Bay. The seawater has a very low resistivity that complicates the interpretation but this model does

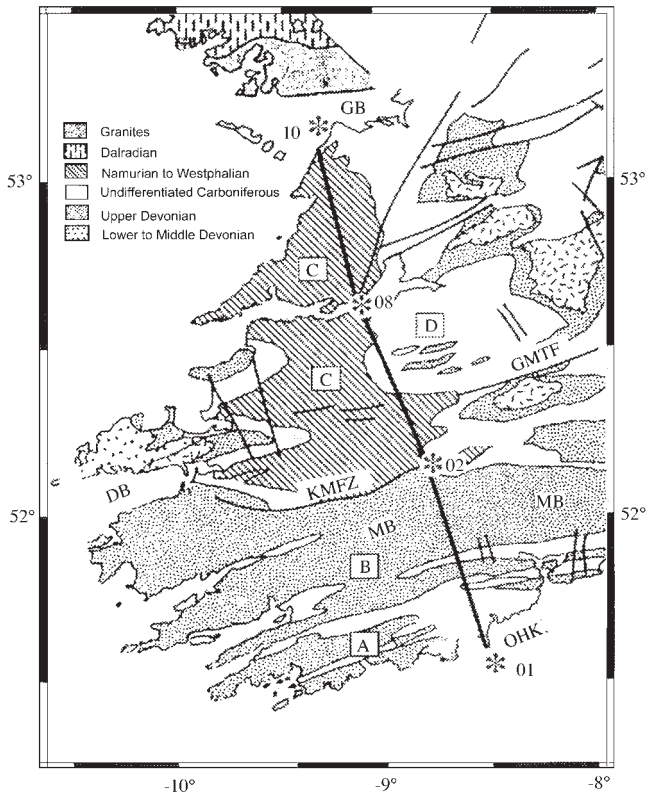

Figure 7. Simplified geology map of southwest Ireland (after Landes *et al*. 2000). The VARNET-96 Seismic Line A is marked from Galway Bay (GB) to the Old Head of Kinsale (OHK). A, marine shale and sandstone (Lower Carboniferous); B, Old Red Sandstone (Upper Devonian); C, shale and sandstone (Namurian); D, limestone (Lower Carboniferous); MB, Munster Basin; KMFZ (Killarney – Mallow Fault Zone); GMTF, Galtee Mountains Thrust Fault; DB, Dingle Bay.

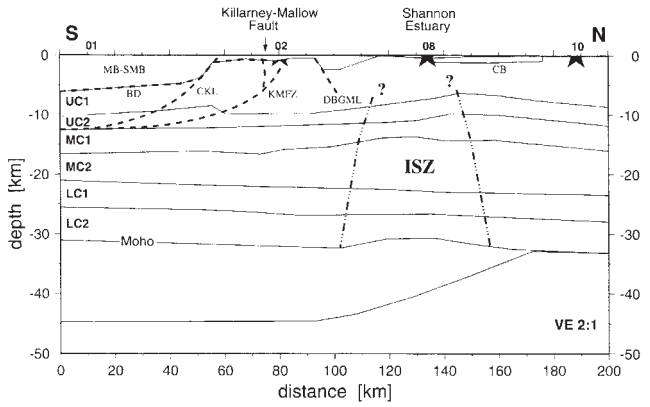

Figure 8. Tectonic interpretation of VARNET-96 Seismic Line A (after Landes *et al*. 2000). SMB, South Munster Basin; BD, Basal Detachment; CKL, Cork-Kenmare Line; DBGML, Dingle Bay–Galtee Mountains Line; CB, Clare Basin; ISZ, Iapetus Suture Zone. Other abbreviations as in Figure 7.

show the existence of relatively low resistivity faults in the crust at the northern end of Dingle Bay (Dingle Bay Shear Zone) and at its southern end (Coomnacronia Fault). The results for magnetotelluric profiles almost coincident with the seismic lines corroborate some of the main features in the seismic lines and are the subject of a paper in preparation (Brown *et al.* 2001). One interesting feature of this work is that the south-dipping low resistivity zone associated with the Iapetus Suture (Figure 3) appears to extend from west of the Shannon Estuary through the Irish Midlands and eventually east of Southern Scotland. Whilst most of the electric currents in the seawater around Ireland and the UK circulate around the more resistive land, the low resistivity Iapetus Suture acts as a 'short-circuit' for channelling electric currents between the west coast of Ireland and the east coast of Scotland.

Other geophysical work has focused upon the structure of the continental margin off the west coast of Ireland. For example, Eve Daly and Fiona Grant in NUI, Galway, along with Royal Holloway College and Oxford University, have been investigating the relationship between the gravity field and bathymetry in order to assess the rheology of the continental margin. The lithosphere is modelled as a thin elastic plate subjected to loading from above (seamounts or sedimentary basins) or below (crustal thickening and/or magmatic underplating). The spatial distribution of these loads can be decomposed into a series of sinusoidal loads with different wavelengths using Fourier analysis. It turns out that the correlation between the bathymetry and gravity field is a function of wavelength and is a measure of the effective elastic thickness of the lithosphere. The effective elastic thickness is a good indicator of the rheology of the lithosphere and, when combined with other data, can be used to infer tectonic processes. Figure 10 is a simple cartoon of how the model is constructed. We assume that a sinusoidal (single wavelength) topographic load, Hi, is placed upon the lithosphere surface (top left), causing it to flex as shown in the bottom left of the diagram. We place an additional single wavelength load, Wi, at the crust-mantle boundary and this causes the lithosphere to flex as shown in the middle of the diagram. These two processes can be added together to give the final surface topographic load, H, and the final sub-surface topographic load, W. The variable topography on the surface and sub-surface will give rise to gravity anomalies. We can repeat this process for loads with different wavelengths. When we perform our Fourier analysis on the observed bathymetry and gravity, we can look at the coherence between the gravity and bathymetry and this is indicative of the effective elastic thickness and the ratio, f, of the initial sub-surface to surface load (Wi divided by Hi). The preliminary results using this new technique on offshore Ireland are quite dramatic. The Rockall Trough appears to have a low elastic thickness (< 8km) and the Hatton Margin appears to have a high f ratio. Some of the seamounts in the Rockall Trough also appear to have unusually dense cores. The tectonic significance of these results will be published elsewhere.

Conclusion

The magnetic, magnetotelluric, gravity and seismic interpretations can be combined to infer a self-consistent but incomplete story of how different rock types have been distributed beneath central and southern Ireland. This is one aspect of how science evolves. In our attempts to re-construct the controlling state-of-affairs we must continually ask new questions that demand more data from which we can construct new theories. In so doing we can deepen our understanding of the dynamics of the Earth's surface and our appreciation of the resulting landscape.

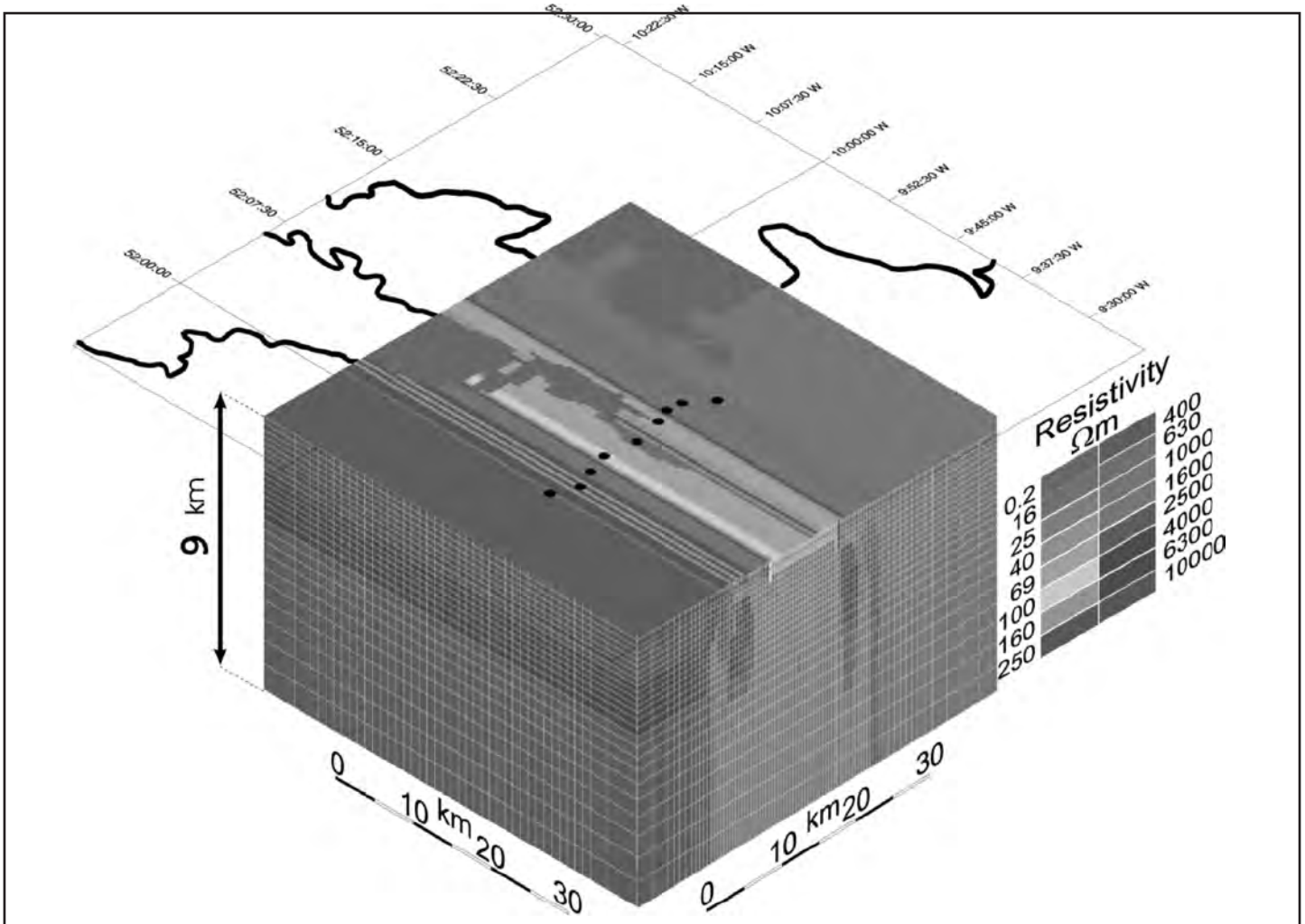

Figure 9. A simple 3D resistivity model for 9 magnetotelluric sites (black dots) at the east end of Dingle Bay. The eastern face shows evidence of low resistivity (~250Ωm) zones extending several km deep in crust with a typical resistivity of ~1600Ωm. The zones at the northern and southern shores of Dingle Bay are probably associated with the Dingle Bay-Galtee Mountains Line and the Coomnacronia Fault respectively.

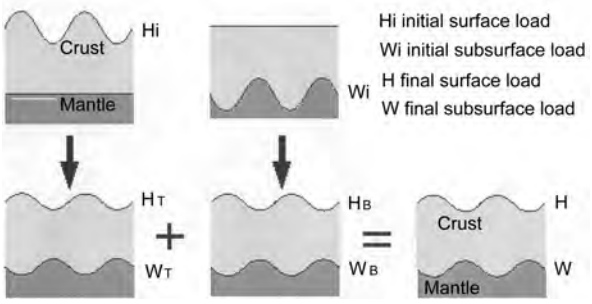

Figure 10. The flexural isostatic model for gravity and topography/bathymetry. See text for explanation.

Acknowledgement

The author acknowledges the help and co-operation over many years from two excellent colleagues who have died recently - Professors Ron Girdler and Brian Jacob. They will be missed in the UK and Irish geophysical community.

References

Armstrong G D, 1997, *Potential field signatures and flexural rigidity of the lithosphere in Ireland.* PhD Thesis, NUI, Galway.

Brown C & Whelan J P, 1995, Terrane boundaries in Ireland inferred from the Irish Magnetotelluric Profile and other geophysical data. *Journal of the Geological Society, London,* **152**, 52 –534.

Brown C & Williams B, 1985, A gravity and magnetic interpretation of the structure of the Irish Midlands and its relation to ore genesis. *Journal of the Geological Society, London*, **142**, 1059–1075.

Brown C, Denny P, Haak V & Bruton P, 2001, Caledonian and Variscan Structures in VARNET – MT: Interpretation of Magnetotelluric Data over Southwest Ireland (in preparation).

Landes M, Prodehl C, Hauser F, Jacob A W B & Vermuelen N J, 2000, VARNET-96: influence of the Variscan and Caledonian orogenies on crustal structure in SW Ireland. *Geophysical Journal International,* **140**, 660-676.

Lowe C & Jacob A W B, 1989, A north-south seismic refraction profile across the Caledonian suture zones in Ireland. *Tectonophysics,* **168**, 297-318.

O'Reilly B M, Readman P W & Murphy T, 1999, Gravity lineaments and Carboniferous-hosted base metal deposits of the Irish Midlands. In: McCaffrey K J W, Lonergan L & Wilkinson J J (eds). Fractures, Fluid Flow and Mineralisation, *Geological Society, London, Special Publications*, **155**, 313-321.

Book reviews

What drives Metamorphism and Metamorphic Reactions? by P J Treloar & P J O'Brien (eds), 1998, Geological Society Special Publication No 138, The Geological Society, London, 287pp, £69.00 (hardback) ISBN 1862390096.

This volume is a collection of 14 papers that derive from a meeting at Kingston University in 1996. The meeting was convened by the editors on behalf of the Metamorphic Studies Group.

It has long been known that the ultimate driving force behind metamorphic processes is heat, and a great deal of work has established the principles of contact metamorphism and the link between the emplacement of igneous bodies and the metamorphism of country rock. This volume sets out to examine the processes that cause regional metamorphism and attempts to explain its driving force(s).

Previous studies have shown that metamorphic conditions are anomalous and the variety in possible driving forces is well illustrated by these papers. The authors cover a wide range of subjects from metamorphism in the Himalayan and Variscan orogens to Ultra High Temperature metamorphism, low pressure crustal anatexis and chemical and volume changes, to name but a few. It becomes clear that much of what appears to be chaotic about metamorphism is merely complex! Our knowledge of metamorphic processes is more complete than it was in the past and we are better able to quantify the processes more accurately; but much remains to be explained. Of particular note is a paper on phase diagram animation. On the basis that a picture is worth a thousand words – a moving picture must be worth many more. The authors provide a full description of their approach to the subject and include a well-explained code for the construction of compatability diagrams and the phase diagram movies. They have included a URL to allow access to the movies associated with the paper and I highly recommend a look at them.

The papers are all well presented and include well laid out, although complex, diagrams. The comprehensive bibliographies included with each paper provide an ideal reading list for those with a deeper interest in the subject. It is not a book to be read at one sitting and a complete index will direct you to specific subjects. I have to add that it is not aimed at the undergraduate; not being an "easy" book, and I found I needed constant access to Earth Science and other dictionaries. For those who would like to know more about metamorphism, this book is well worth taking out from the library. If you have that deeper interest, it is well worth the money.

Mike Hermolle, BSc Hons (Open)

Panbiogeography - Tracking the History of Life by Robin C Craw, John R Grehan & Michael J Heads, 1999, Oxford University Press, 229pp, £45.00 (hardback) ISBN 0195074416.

This is the eleventh book in the Oxford Biogeography Series edited by A Hallam, B R Rosen and T C Whitmore.

This book is like two books mixed into one. The first is a review of the literature and is heavy going. The second is more like a textbook with case studies and an introduction to panbiogeographic techniques and is a better read. How do you pick out the best bits? The index may annoy you; for example you may be interested in the case study on the Miombo woodland and mangroves found at high altitude. Mangrove appears in the index under E for ecology.

Where do you start? Chapter 1 "What is Panbiogeography?'"seems promising. The second paragraph includes "A reading of this literature reveals enormous confusion over what exactly constitutes panbiogeography." This sums up the chapter. If you must read it, wait until the end.

Chapter 2 "Life as a geological layer" gives you a better introduction to panbiogeography. The case study on "Evolution of the Galapagos Biota" was particularly thought-provoking after my study of "How plate tectonics works" in S267 and "What is the Lithosphere" in S339. Chapter 3 "Ecology, History and the Panbiogeography of Africa" develops the theme and is well worth a read.

Chapter 4 "Mapping the trees of life" is heavy going. It covers phylogenetic systematics and evolutionary processes and would be easier to follow if you have studied S365 Evolution.

Chapter 5 "Tracking the trees of life" develops the use of "tracks" and "nodes" as panbiogeographic tools. I do not think there is enough detail to allow you to start using the tools in your own research. Chapter 7 "Tracks, nodes, biodiversity and conservation" tries to show "tracks and nodes" as tools in the study of biodiversity and conservation. I was not convinced.

Chapter 6 "Towards a new regional biogeography" develops the idea that the present arrangement of floral kingdoms and faunal regions (as presented in S328 Ecology) is only transitory and there are relationships that developed in previous climatic and tectonic settings.

I suggest dipping into this book rather than reading it from cover to cover.

John Mollard BSc Hons (Open)

The dating game: one man's search for the age of the Earth by Cherry Lewis, 2000, Cambridge University Press, 253pp, £17.95 (hardback) ISBN 0521790514.

This highly readable biography rambles the world in the company of Arthur Holmes, described on its dust-jacket as 'greatest geologist of the twentieth century', whose enduring contribution to science was to demonstrate that the Earth was incomparably more ancient than previously believed as well as assigning absolute ages to the geological timescale.

As well as chronicling Holmes' life, copious digressions describe the work of earlier and contemporary geologists whose ideas Holmes developed and, in many cases, challenged; this reads almost like a Who's Who of geology and the budding science of nuclear physics. Much of this material is obviously aimed at the lay reader, but it is a useful reminder for students of geology.

The author paints a vivid picture of Holmes' personal and family life, his employment in Africa and the Far East, his pecuniary, personal and professional tribulations, to the point where the reader heaves a real sigh of relief to read of his appointment as the first Professor of Geology at Durham.

In some ways I would like to have seen a little more of the scientific detail which I thought was rather underplayed. Lewis makes the point that Holmes' vision of developing a geological time scale dominated his life for over fifty years, but the book contains so many other threads that I had no impression of single-mindedness or a driving force behind Holmes' work. Indeed, Holmes appears to have had a very wide variety of geological interests, ranging from the infant theory of plate tectonics to the beginnings of the modern oil industry.

One aspect of the book which irritated me more than a little was a number of minor errors which a good editor ought to have noticed and corrected.

In summary, The Dating Game is a worthwhile read for anyone interested in fuller pictures of the people behind scientific advance.

Anne Burgess MA Diploma Earth Science and continuing student

Exploring Geology on the Isle of Arran by C J Nicholas, 2000, Cambridge University Press, 234 pp, £9.95 (paperback) ISBN 0521635551.

On the face of it, this book looks as if it should be a fascinating study of the geology of the Isle of Arran. It certainly is that, but it was not as I expected. It is set out as a series of 'practical exercises' (almost lessons) that can be carried out in the field and that take you on a geological tour of Arran.

Each exercise has been carefully formatted to be independent (stand alone) or one that can be linked as part of a planned study around Arran. As well as basic fieldwork guidelines relevant to safety, how to work out

an itinerary and basic field skills, Nicholas also provides the reader with practical activities, questions and the theory behind the field evidence. The book also contains the opportunity for anyone who is following his suggested (many of them 'classical') locations to make detailed field notes.

I found this book difficult to read because of its nature. Its format necessitates interaction and involvement for the reader as he guides you to specific locations and pushes you towards conclusions about what you are seeing in the field. It is full of theoretical explanations and black and white photographs and location maps.

If you were planning to explore the geology of Arran or leading a field trip, I think this book would be invaluable and probably necessary. At £9.95 it would be well worth it.

Wendy Owens, continuing ES student

Comet Science by Jacques Crovisier & Thérèse Encrenaz, 2000, Cambridge University Press, 154pp, £14.95 (paperback) ISBN 0521645913.

I found this book a true delight; it is a real *tour de force* of the subject and is quite readable even if you do not have a scientific mind. It is not choked with formulae, physics or chemistry, and for those chapters that do have a heavy science content one is pleasantly surprised when the following chapter contains some truly delightful descriptive text as its main component.

A fascinating introductory Chapter 1 provides the reader with the history of cometary observation from the Chaldeans, four thousand years ago, through to the times of Aristotle, Giotto, Halley and Encke. The authors neatly side-step more recent observations as they are dealt with in later chapters.

The early chapters give an insight into what comets are, their origins and methods of observation. It is not until Chapter 4 that significant scientific notation is introduced and even this is quite manageable and well explained by charts and information boxes. Chapter 5 returns to description with a discussion of the 1986 apparition of Comet Halley, from its re-sighting in October 1982 to visits by European, Japanese and USSR spacecraft in early 1986.

Chapter 6 takes the reader into the science of infrared, radio and x-ray observations of comets, some of which I consider quite hard going for the amateur. Cometary Nuclei is the subject of Chapter 7. There is again a great deal of scientific notation but it is interspersed with interesting text on the subject which makes it very manageable. It is a real delight after struggling through Chapters 6 and 7 to find the following chapter giving an excellent description of the collision of Comet Shoemaker-Levy 9 with Jupiter. The nature of the composition of comets is dealt with in Chapter 9 but like the more scientific chapters previously it is interspersed with some interesting reading.

The final chapter puts comets in their place in the Solar System and has an interesting analysis of where cometary research and exploration is heading.

A really good appendix containing tables of famous comets, asteroids (strangely) and space missions together with an excellent glossary all assist to make this a complete work on the subject. My only real disappointment was the rather poor collection of photographs but, to be fair, the diagrams and drawings are particularly well presented and helpful.

The inside cover of this book correctly describes it as "written in a clear and lively style [that] will appeal to anyone ... professionals and amateurs alike". I can do little better than repeat the words of the ESA Director of Scientific Programmes, Roger Maurice Bonnet who, in his introduction to this work, says, "Readers will appreciate the happy balance between chapters devoted to observation and those devoted to techniques …" I completely agree.

Mike Moores continuing ES student

Prospects for Sustainable Energy: A Critical Assessment by Edward S Cassedy, 2000, Cambridge University Press, 284pp, £45 (hardback) ISBN 0521631203.

The book aims to help the reader assess the prospects and reasons for, significant amounts of the world's energy needs being supplied from renewable, non-fossil fuel sources. It considers the historical uses of such energy and concentrates on the technical feasibility, environmental impact, economic, political and marketable implications of a range of alternative energy sources which could replace, or work alongside, fossil fuels with their limited lifetimes and environmental considerations. Much of the assessment of these alternative fuels is placed in the geographical areas of the industrial world, especially the USA and Europe, but their part in providing energy for the developing countries is also of importance.

The book is divided into three parts:

Part 1, the Introduction, concentrates on the limited life and adverse impacts of fossil fuel burning, which by the late 1990's accounted for much of our global energy needs with its increasing use as an energy source in rapidly developing countries. It introduces the environmental arguments for the continued development and expansion of sustainable fuel options.

Part 2, the main body of the book, has chapters on each of the main alternative energy sources: solar energy, biomass energy, wind power, hydroelectric power, geothermal energy, ocean energy, nuclear fusion and hydrogen fuel from renewable sources. It also includes a chapter on energy storage, a vital component of renewable energy usage. Each of these chapters considers the relative usefulness of the fuel source, how it is presently produced and possible future improvements. The potential use for each energy source is considered both geographically and politically. Methods of production are set out with good technological detail using easily digested flowcharts and diagrams. Economic costs of producing the fuels are considered, including initial set-up costs, and then large and small scale production costs are estimated to give comparison with fossil fuel alternatives, often as a cost per unit of energy. Some detail of current R & D for each fuel is included in these chapters.

Part 3 concentrates on summary assessments for the various non-fossil fuel technologies, with the final chapter giving more detailed R & D information, mainly on Europe and the USA and other industrially developed countries.

This book provides a comprehensive background and is a good reference and source book for both students and those working in the related fields of global energy needs and global climate impacts. It also provides useful detail for scientists involved in their government's fuel policy decisions. It would be useful to individuals or groups wishing to provide their own alternative energy source for environmental or geographic reasons. The book is well illustrated throughout.

Valerie House BSc Hons (Open)

Catalogue of Meteorites (fifth edition) by Monica M Grady, 2000, Cambridge University Press, 690pp, £90 (hardback including CD-ROM) ISBN 0521663032.

This is the 39th publication in a series of Natural History Museum meteorite catalogues beginning in 1847 with a 3 page pamphlet listing the (then) British Museum's 62 specimens and now covering 22,507 meteorites weighing 2kg and including the catalogue on a CD-ROM.

The catalogue can be regarded as comprising sections:

Introduction – 4pp describing the formats of the individual entries, instructions for the CD-ROM and addresses and abbreviations;

Summary tables – 4 pp Meteorites by Classification: Stones Chondrites, Stones Achondrites, Stony-Irons and Irons, Totals grouped by Falls and Finds and the NHM Collection, Geographical Listing;

List by Classification – 16 pp;

List by Geographical Locations – 18 pp;

Catalogue – 491pp containing the 22,507 entries;

Tables – 144pp tabulating the meteorites by find in 4 regions, Antarctica, Nullarbor Australia, Roosevelt County New Mexico and the Sahara.

The entries comprise as much information as is available to fit in a standard format: Name, Find/Fall information, Classification, Synonyms, Recovered weight, Reported, Main text with references by author and year (but not journals), Distribution of fragments and Specimen(s) in the Natural History Museum. The lack of full citation is unfortunate but inclusion would render the Catalogue too big.

Inclusion by Find and/or (observed) Fall only has an unexpected effect. The Tunguska fall is included but the other two major impacts that we all know, the Barringer crater and Chicxulub, which were not observed do not appear. Curiously there is an entry for Coon Butte, a 2.75kg chondrite, "found about a mile W of Coon Butte (= Meteor Crater)".

This is mainly a reference for the specialist or post graduate researcher. The level of detail is excellent and is possibly too much for most students. As a reference, however, the Catalogue and especially the summary tables can be useful to any OU student studying courses such as S267, S269 and S281 that have significant meteorite related contents. To an inveterate encyclopaedia dipper the joy of the Catalogue is the volume of pure information. For example, on one page we have three Allan Hills, Antarctica finds – one lunar and two Martian; or the Borodino chondrite that fell 5th September 1812 and was reported "to have been observed by a soldier on guard before the battle of Borodin", I do not remember Tolstoy mentioning this!

The Catalogue is a beautiful product with good quality covers, paper and printing. At £90 it is designed to be a reference for Research Departments, Libraries, etc. and only the most highly specialised individuals will buy. This is a pity; if it were available in paperback at the same price as my Earth Science dictionaries I would buy it today.

Bill Willows BSc Hons (Open)

Tectonic Consequences of the Earth's Rotation by Robert C Bostrom, 2000, Oxford University Press, 266pp, £60.00 (hardback) ISBN 0195090284.

The stress ellipsoid emblazoned on the front cover of this book provides a strong hint as to its content, namely the study of the complex effects on the Earth's tectonics of stresses generated by tidal dissipation. The book defines three categories of tidal dissipation. Firstly, there is marine dissipation which is thought to principally take place in shallow-sea regions. Secondly, there is solid-Earth dissipation which takes place under two distinct types of tidal action: an oscillatory deformation that causes periodic bulging accompanied by twice-daily subsurface pressure pulses, and a progressive induction of incremental circulation, termed vorticity. Finally, there is solid-Earth/marine interactive dissipation illustrated by the ocean-ridge system.

The book's first two chapters comprise a very readable overview of tidal distortion, true polar wander, a historical perception of Earth rotation and global tectonics. A difficult chapter then follows that offers an explanation of how the Earth's tectonics relate to the static and mobile 'bulges' which are induced by tidal deformation, dissipation and distortion. Subsequent chapters, although far from easy reading, are more 'user-friendly' and cover the fields of tidal action, plate motion, data-indicated flow, 'absolute' motion, lithospheric mobility and true polar wander. The book's final chapter discusses observational problems encountered during the detection and measurement of the effects of tidal forces and provides a 'health' warning about the care which must be taken when analyzing associated data.

The book contains only one photographic plate but is generously illustrated throughout with black and white diagrams and computer-generated images. My only real criticism of the book is the poor quality of a number of these illustrations which typify those that often accompany advanced texts. Many of the original diagrams and most of the images were almost certainly in colour and this book would have greatly benefited by the retention of some of them in that medium.

Sections of this book demand some post-graduate earth science knowledge and there is some moderately advanced mathematics scattered throughout the book, although none is essential to the tectonic 'plot'. The author states that the book is "not intended to prove a connection between the Earth's rotation and geotectonics. Instead, it is intended to review evidence that a connection may exist." Despite the undoubtedly difficult nature of much of the text, in my opinion the book provides a fascinating and generally well written treatise about one of the most intriguing facets of the Earth Sciences.

Tony Marter, continuing Earth Science student

A Revised Correlation of Ordovician Rocks in The British Isles by R A Fortey, D A T Harper, J K Ingham, A Owen, M A Parkes, A W A Rushton & N H Woodcock, 2000, The Geological Society. Special Report No. 24, 83pp, £18 (paperback) ISBN 186239069X.

The Ordovician System was founded by Lapworth in 1879 on the basis of British successions. By modern standards the System was unsatisfactory, eg boundaries at unconformities. Lapworth himself expressed uncertainty about defining the base of the Ordovician.

The basic System has endured and over the last 120 years it has been improved and international correlations are being agreed. This report follows on from the corresponding GS report of 1972. In the intervening period there has been much work on all aspects of the System including reinterpreting in terms of plate tectonics and terrane analysis.

The report begins by discussing the definitions of the chronostratigraphic divisions of the Ordovician followed by discussion of the British and Irish terranes of the period. Individual chapters are then devoted to the major outcrop areas: South and North Wales, Welsh Borders, Southern England, Northern England, the Southern Uplands, the Scottish Midland Valley, Highland Border Complex & Grampians and Ireland. Finally, international correlation is discussed but not in great detail.

The Ordovician was marked in Britain by the Iapetus closure and thus was one of Britain's most important periods. I found the chapters on stratigraphy and terranes (only 11 pages in all) valuable in shedding additional light on the historical geology of S236 and S339. The stratigraphy also illuminated my understanding of the Ordovician and of the problems and processes of stratigraphic correlation. For those who are interested in going beyond Course Units the report is worth obtaining just for these Chapters.

The discussion of outcrop areas takes the reader much deeper into the stratigraphy with a total of 125 stratigraphic columns accompanying correlations and environmental interpretations. Together with the extensive bibliography this is clearly invaluable to the specialist/researcher. It is also valuable to visitors and field trippers, especially leaders. For all of these, the Report could be used for up to date information additional to the British Regional Geology series.

The Report is reasonably priced. If the Ordovician is your thing or your home area lies in a major Ordovician area, this would be a worthwhile addition to your personal geological library.

Bill Willows BSc Hons (Open)

Discovering Geology: Fossil Focus

Brachiopods by Beris Cox & Ian Penn, 2000, BGS, A3 folded, £1.95 ISBN 0852723466.

Corals by Ian Wilkinson & Colin Scruton, 2000, BGS, A3 folded, £1.95 ISBN 0852723490.

Fish by Ian Wilkinson & Sally Young, 2000, BGS, A3 folded, £1.95 ISBN 0852723504.

These are three new titles in the excellent Earthwise Publications series. They are attractively presented, well illustrated fold-out laminated sheets and each one summarises a particular fossil group.

Brachiopods
An introductory general description is followed by a clear and well illustrated account of their morphology. This is followed by an excellent section on how fossil brachiopods are useful tools for the geologist. A painting of a Silurian seascape is reproduced which shows the distribution patterns of brachiopods, corals, bryozoa, crinoids and gastropods in different depths of water. Inset paragraphs give definitions of phylum, palaeoecology, facies and other terms. An explanatory diagram shows the relative diversity of the phylum through time with each geological period shown in a different colour. On the back of the folded sheet is a section headed Brachiopods: folklore and fact and includes fascinating little snippets such as the origin of the common names, lampshells, seabean sprout and stone swallows among others.

Corals
After a general description the authors focus on the three orders of corals most frequently found as fossils: rugose, tabulate and scleractinian. The text is illustrated with photographs of fossils and living corals, including a picture of a living coral reef in the Seychelles. A section deals with their environment and there are excellent diagrams showing the formation of coral reefs. A geological time chart shows their distribution from the Precambrian to the Quaternary and another chart of the Lower Carboniferous shows how corals can be used in biostratigraphy. There is a section headed Corals: fact or fiction? Under this heading there are three items: The Coral Clock explains the use of growth rings to deduce the number of days in a year in different periods; Starstones describes a fanciful idea from the 17th century that a certain colonial coral was related to the Celestial Bodies; and, lastly, the Earliest Corals suggesting that *Charnia* belongs to the Octocorals.

Fish
A general description is followed by sections about Jawless fish, Jawed fish, Cartilaginous fish, Bony fish, Lobe-finned fish and Ray-finned fish. An attractive drawing across the centre of the folded out sheet shows fish through time from the Silurian through Devonian, Jurassic, Cretaceous and Palaeogene. A geological time chart, Fish through time, shows the evolution of the main groups from the Cambrian when what may have been the nearest ancestor to the fish, the chordate *Pikaia*, inhabited deep marine water. The last section, Fishy tales, features Tongue stones which are actually the teeth of fossil sharks – Pliny the Elder described these and they were thought to have medicinal properties and we are told that some people still carry them as a talisman against bad luck; Toad stones which were thought to have formed in the head of a toad but are really the teeth of the fossil fish *Lepidotes*, and the section ends with a paragraph about the living fossil *Latimeria* and the coelacanth *Macropoma*.

This series, for the non-specialist, gives a good introduction to fossils and is really good value at £1.95 per sheet.

Elizabeth Maddocks BA(Open)

Great Comets by Robert Burnham, 2000, Cambridge University Press, 228pp, £14.95 (paperback) ISBN 0521646006.
The book begins with a forward by David Levy (of Shoemaker-Levy 9 fame) introducing his fascination with comet hunting.

The main body of the book begins with an introduction into the historic comets and their effects on civilisation. The section then leads into the early astronomers and their discoveries, the formation and construction of comets. It explains the mechanics of the orbits and what causes them to change to close approach (to the sun) orbits rather than their usual orbits. He then gives a description on what makes a comet great.

Then there are chapters on the following comets, Hyakutake 1996 and Hale-Bopp 1997. Both these chapters contain many good photographs some on professional telescopes and some eye opening 'amateur' photographs using SLR cameras with quite normal lens. The trick seems to be to use a very fast film (1000ASA plus) and exposures from 15 seconds to 8 minutes. Remembering how miserable some of the comets looked to the naked eye and even with binoculars, I think an experiment is due when the next comet turns up.

The next chapter covers the spacecraft investigation of comets starting with Giotto on the 1986 Halley and leading on to the proposed flights up to 2015. There are descriptions and photographs of the Giotto encounter with Halley and information on the science proposed for the forthcoming missions. Stardust should perform the first 'geological' mission taking samples from Wild-2 in 2004 returning with them in January 2006.

Next there is a very non scientific chapter on the more bizarre effects of comets on the population, but it really is a bit out of place.

The next chapter covers the effects of impacts with earth and what is being done to obtain warnings of collisions with not only comets but also asteroids. Although underfunded at present, the computerised search involved with this looks as though it will remove the possibility of amateur discovery in the future, so if you want your name on a comet you had better start looking now. The final chapter gives some internet links for information on comets and the space missions; however, knowing the transient nature of the www these may already be out of date although I have not checked.

It is quite a good book and it is very good at giving the photographic information for many of the photographs.

Alan Hamilton BA Hons (Open), interested amateur

Earth Systems: Processes and Issues, by W G Ernst (ed), 2000, Cambridge University Press, 566pp, £27.95 (paperback) ISBN 0521478952.
This is a textbook for introductory courses in Earth systems science and environmental science at first-year university level.

The large size may be daunting, but its content is highly accessible, and it is well organised into 33 separate and well illustrated chapters. The team of 19 authors are mostly from the Department of Geological and Environmental Sciences at Stanford University where W G Ernst is a professor. The first half of the book gives a thorough introductory presentation of the science and the environmental processes. The second half carries this scientific understanding through into a well-balanced exploration of the social, economic and policy implications. It also explains how political processes usually distort or evade global environmental issues.

This book would be a useful companion to the OU Earth Sciences course books. It avoids their greater depth and specialisation but provides a coherent overview of the processes and issues, backed by a depth of evidence and case studies that is sufficient for its purpose. The text is slightly marred by word-processing errors which seem to be an inevitable consequence of current book production pressures and a general expectation that bugs will be fixed by revision in future editions. There is also some rather pompous academic verbiage in places.

For me, the high point of the book is Chapter 26: Steps from Environmental Science to Effective Policy by Lawrence H Goulder (see below). My low point was in Chapter 2: Physical Geography which errs towards the "geographical determinism" that has long since destroyed geography as a serious academic discipline in the USA.

Lawrence Goulder's chapter provides a short and clear analysis of the social pressures that pervade environmental policy. The gist is that having read the first half of the book you might think that the science of global warming etc was hard. But the science is only the first step towards appropriate action. Environmental action costs money, therefore it becomes an economic problem. But the economics are difficult: ascertaining the costs and benefits is not easy, and environmental benefits are mostly "externalities" to be addressed via public policy, which means that environmental action becomes a political issue. But the politics are difficult because of limited public understanding together with "mobilisation bias" which tends to favour special interests in political processes instead of the general public good. The message is that anyone who really cares about global environmental issues needs to get beyond the science and into the economics and politics – Earth scientists please take note.

John Brenner MA (Cantab), continuing Earth Sciences student

Looking into the Earth: An Introduction to Geological Geophysics by Alan E Mussett & M Aftab Khan, 2000, Cambridge University Press, 470pp, £26.95 (paperback) ISBN 052178574X.

The theme (of which the authors never lose sight) is how to select an appropriate geophysics strategy and, in pursuit of this, lots of quite recondite areas of earth science are explored and seen from a different perspective which definitely aids understanding. The stated intention is not to make every reader into an expert but to enable those actually involved in any area that uses geophysics to select the technique appropriate for a given situation. I think they succeeded. In fact they have catered for a much wider audience than my words might suggest, for each chapter starts with an introductory paragraph so that the reader/user knows what to expect and ends with questions to test one's understanding. What does the reader need to bring to the book? Well, a reasonable basic knowledge of either geology or physics would make for a fairly straightforward approach but I suspect that those intelligent and interested but not terribly knowledgeable in either discipline could largely ignore the maths and just read it as a straight text. It is written in good, clear English with lots of good analogies to aid understanding and lots and lots of splendidly clear diagrams - the explanation of fault-plane solutions for instance struck me as better than the one I dimly recall from my OU units. Which brings me to another point of especial interest to earth science students. Due to the nature of its target audience(s) there are some very clear explanations of various bits that I don't recall seeing discussed in OU texts. I would think that anybody tackling third level courses might well find this a very useful adjunct. The price is not high for a textbook and not one of those 470 pages is wasted which makes for a lot of useful information. Those studying at lower levels would certainly be interested in this book and I cannot really imagine the average OU student having any real problems with it (do we ever?).

The book does cover, one way or another, just about every aspect of earth science, for there are applications for geophysics that had not previously occurred to me. It finishes with a number of real life case studies - describing the problems, why geophysics was seen as an aid and how the appropriate techniques were selected. These case studies cover a very wide range of topics; K/T extinction boundary, hydrogeology, Etna, landfill sites and archaeology to name but a few. Good book. Read it. Buy it?

Jennifer S Holt BSc (Open), postgraduate researcher at the University of Lancaster

Impact Cratering: A Geologic Process by H J Melosh, 2000, Oxford University Press, 245pp, £32.50 (paperback) ISBN 0195104633.

For me the events which took place between the discovery of the periodic comet Shoemaker–Levy 9 in March 1993 and its ultimate demise as a series of impacts into Jupiter between 16 and 22 July 1994 left a lasting impression and a desire to find out more about such events. Continuing work by Alvarez and others and the subsequent publication of events surrounding the impact which formed the Chichxulub crater has raised the profile of the effect of such impacts on planetary development. However, in spite of the subsequent attentions of Hollywood to the subject, it has been difficult to find publications which deal with all the geological and physical processes involved except at superficial levels.

This book gives a clear and concise account of every aspect of the process of impact cratering and as such fills an important gap in the study of planetary science by bringing together the historical background, physical and mechanical processes involved in impact cratering and its influence on planetary evolution. It includes chapters on crater morphology, cratering mechanics, ejecta processes, scaling of crater dimensions, cratered landscapes and atmospheric interaction. For those who have completed S281(Astronomy and Planetary Science), this book follows on from the section on cratering and indeed some of the photographs in Chapter V (Cratering Mechanics – Excavation Stage) will be familiar as they relate to the experiments of P H Schultz carried out using the Ames Vertical Gun Range and subsequently reproduced in an OU video.

As is only to be expected with a subject as dependent on material interaction as this, some of the chapters such as Chapter III (Stress Waves in Solids) are dependent on the understanding of the maths behind the processes. However, the derivation of equations used are explained adequately and clearly in the appendices: Appendix I Derivation of the Hugoniot Equations and Appendix II Equations for the State of Impact Cratering.

This book deals well with the chosen subject and is aimed at the postgraduate and upper undergraduate levels. Certainly anyone who has completed S281 should be able to make use of it as a basis for further study into the subject and the interested layman should find it helpful even by avoiding the more mathematically based chapters. It is certainly a book which I will buy and refer to on a regular basis.

John Jaggard BEd (Hons) BSc (Open)

From the Beginning by Katie Edwards & Brian Rosen, 2000, Natural History Museum, 72pp, £7.95, (paperback) ISBN 0565091425.

This book forms part of a series of books published by the Natural History Museum. The books are aimed at those with only a little scientific background or older children, but are not so simple that they are unsuitable for OU students. They are attractive with numerous colour photos and diagrams with simple, easy-to-read text. The books were written to accompany exhibitions at the Natural History Museum and the series is reasonably priced.

This book covers 'The Big Bang', our solar system, meteorites, early Earth, crust and water, evolving life, atmosphere, dating the past, what are fossils, the divergence of life forms from simple through to man, extinctions, ice ages and the future, all in just 68 pages. Many of the pages have a very useful time-line at the top. Even OU graduates might find a few things they did not know; for instance, that *Anomalocans* is a Precambrian fossil.

Although generally good, there are a few mistakes in this book. The key on page 68 is wrong, the blue labelled 'greenhouse' and the red 'icehouse' world are obviously the wrong way round. On page 16 stromatolites are said to date from 3400Ma, when they probably date back to 3500Ma (the Pilbara Western Australia according to Schopf 1992). Mass Extinctions, especially at the end of the Cretaceous, are dealt with well giving a comprehensive balanced explanation.

Wendy Hamilton ex OU Tutor

Stone Quarry Landscapes – the industrial archaeology of quarrying. by Peter Stanier, 2001, Tempus Publishing, 160pp, £16.99 (paperback) ISBN 0752417517.

As geologists we are always looking at rocks, the foundation of the landscape. The methods of extraction, the uses to which they have been put and the remnants of past extractive processes are the basis for this book.

This is the latest offering by Peter Stanier who penned the *Shire Album on Quarries and Quarrying* some 15 years ago. This new book helps bridge the gap between those interested merely in the product and those drawn to the evidence for the methods of production.

With 20 chapters the author uses the opening four to introduce the topic, then devotes a chapter each to 16 English case studies. Of these, 11 are in the South. The expected centres of Portland, Purbeck and Bath rub shoulders with Peak Millstones, Wiltshire Sarcens and Clee Hill Roadstone. Honister Slate, Ham Stone, Cornish granite and slate are covered, as are the important Chalk-based lime industries of South East England.

These studies vary in length with a piece on the National Stone Centre a couple of pages long, the micro-granite of Threlkeld in Cumbria has 4 pages, whilst that on Hills and Holes, of which Barnack in the East Midlands is the most well known, has 5 pages. The author gives away his origins with an eight-page section on the Moorstones of the Southwest, as well as eight pages on the deeper granite quarries of Haytor. As a

native of Dorset I appreciated the use of 27 pages to examine the extensive Portland and Purbeck stone industry in my home county.

The text includes detailed descriptions for some localities and annotated maps so that the interested reader can visit the relevant spot to examine the remaining evidence. As a minor point the individual site maps do have a scale but lack an orientation arrow so one assumes that North is towards the top of the page! However, I will definitely visit the Museum of Bath at Work when next in the city and will also attempt to trace the line of the 18th century incline on Bathampton Down.

There are 6 pages of very useful references for those who would like to read a little deeper, as well as a 3 page index. With 95 well-chosen black and white illustrations and 30 excellent colour plates one cannot argue with the quality of reproduction.

The only criticism I have is with the cover – a two-view affair utilising two colour plates from inside. They look good on the quality paper inside, but on the card cover they do not do the contents of this interesting, informative and very readable book any favours! I am also of the opinion that the design of the cover will not win the publishers any prizes either! However, one does not judge a book by the cover and this title will be a useful addition to the shelves of geologists, local historians and industrial archaeologists alike.

I feel OU Earth Science students in particular will appreciate the well-written text and the clear examples that may be explored independently in the field. The author admirably links rocks and their uses and in doing so helps break down the barriers between geology and the related disciplines of industrial archaeology and local history. We would do well to remember that the only reason we have for man-made exposures, quarries, is because the product has an economic use for society. If more folk appreciated this fundamental point there may well be more interest in the landscape as a whole.

As both a geologist and museum curator I whole-heartedly support such an approach!

Tony Cross Earth Sciences Associate Lecturer

Volcanoes of Europe by Alwyn Scarth & Jean-Claude Tanguy, 2001, Terra Publishing, 256 pp, £19.95 (paperback) ISBN 1903544033.

Do you want to be "encouraged to take an active, informed interest in some of the most sublime and fascinating features in the natural world and, especially, to go and see them"? This is the mission of 'Volcanoes of Europe'.

On the European plate, there has been volcanic activity during the last 10,000 years in a variety of locations: the Azores, Iceland, Canary Islands, southern Italy and the Aegean Sea, together with the Auvergne in France and the Eifel in Germany. These in turn are related to a wide variety of plate tectonic settings: the Mid Atlantic Ridge, hotspots and rifting, collision and subduction and some enigmatic! All are catalogued, together with comprehensive, up-to-date individual bibliographies, plentiful maps and diagrams, and colour and B&W photographs. A real whet to the appetite!

The authors have wide experience of volcanology and of scientific journalism on which to build. In this, the second of Terra Publishing's titles, they not only set out to catalogue the broad state of knowledge of European volcanoes at the end of the 20th century but also to indicate the 'gaps' – topics where fruitful research could be carried out.

I know three of the areas personally: the Canary Islands, the Eifel, and the Auvergne. Keen to see how their descriptions measured up against my own experience I was not disappointed, though sorry that the book was published before the most recent set of papers on Tenerife appeared in the Journal of Volcanology and Geothermal Research (December 2000). However, the bibliographies provide a sound base for research.

Three sections describe the Mediterranean (Italy and Greece); the Atlantic (Canary Islands, Azores, Iceland and Jan Mayen); and northern Europe (France and Germany). A short glossary is handy if you cannot tell your mugearites from your benmoreites, whilst a multi-lingual list of terms for volcanic features helps in understanding their names: did you know that the Icelandic for aa is apalhraun? Finally, if you, like me, are planning your next trip(s) you can consult the list of historical eruptions, arranged by location, to check the chances of seeing some activity!

I have ordered this from Terra and also put a couple of others in their 'Classic Geology in Europe' series on my wish list: Auvergne (Cattermole), and Canary Islands (Carracedo and Day). They have also published Iceland (Thordarson and Hoskuldsson), Italian Volcanoes (Kilburn and McGuire), and The north of Ireland (Lyle).

Linda Fowler BA (Hons) Open, FGS, OU tutor

Tsunami – The Underrated Hazard by Edward Bryant, 2001, Cambridge University Press, 320pp, £19.95 (paperback) ISBN 052177599X.

Tsunami have occurred along the world's coastlines, on reservoirs or lakes or inland seas and inside coral barriers. They are presently happening and will occur in the future. Their history, via records, observations, myths and legends, is appropriately included.

The book is well structured and is set out in 4 parts, with the contents pages outlining the contents of each chapter.

Part 1: Tsunami as known hazards, covering the introduction and tsunami dynamics (and the bulk of the equations, together with lots of statistical information).

Part 2: Tsunami formed landscapes – depositional and erosional signatures in coastal landscapes, coastal landscape evolution (including catastrophism).

Part 3: Causes of tsunami:

- Earthquake generated: seismic activity is the most common cause (82.3% of all known tsunami in the Pacific Ocean)
- Great landslides
- Volcanic eruptions – 4.6% of all known tsunami
- Comets and meteorites

Part 4: Modern risk of tsunami:

- Areas of risk
- Warning systems, including where to go and what to do! Advice given is OK unless it is an asteroid or comet, when thoughts of 'Armageddon' and Bruce Willis spring to mind!

A great deal of the examples given are from the coast of New South Wales, Australia, perhaps as this is local territory for the author. In saying that, examples are also given from around the world to ensure all causes and features are covered.

All photographs and diagrams are in black and white and are of good definition so the features being illustrated can be clearly seen. There are lots of good diagrams throughout the book to explain and clarify the text.

Along with the text mathematical descriptions of tsunami and their dynamics are provided as equations, and most of the material presented in the book can be understood without any detailed understanding of these formulae. If you do want to dip in further to these formulae, a list of symbols used, together with Greek symbols and their meaning, is presented.

At many times during my reading of this book, I felt that just about any landform could be created as the result of a tsunami. I had to convince myself that this was not, and is not, the case.

I set out to read this book from cover to cover for this review and soon started to lose enthusiasm for such an extensive and interesting process. Personally, I feel it is better to use this book as a 'dip into as needed'-type book. Any cross-referencing is effected via the comprehensive index so you won't lose out. If tsunami do something for you, buy it! If not, borrow this copy to enhance your knowledge.

Carol Warcup BSc Hons (Open)

Origin of Igneous Rocks: The Isotopic Evidence by Gunter Faure, 2001, Springer-Verlag, 496pp, £51.50 (hardback) ISBN 3540677720.
The decay of radiogenic isotopes can provide a wide range of data from which the origin of igneous rocks may be deduced: whether they are primary melts from the mantle or the result of melting of crustal rocks. All S267 students will be aware of the relevance of rubidium and strontium in this context, but these are by no means the only isotopes explored. Faure's book also examines the influence of neodymium, lead and oxygen in the genesis of igneous rocks.

By first looking systematically at the way in which radiogenic isotopes are used, at fractional crystallisation, isotope evolution and isochron derivation, the reader is lead through the processes which s/he will need to understand before embarking on studies of the origins of specific igneous rock provinces: mid-ocean ridges, island arcs, subduction zones, flood basalts and continental igneous rocks.

The book is packed with diagrams, sketch maps and equations to aid understanding. The many different case studies from each type of province enable comparisons to be made, similarities to be compared and differences to be evaluated. Investigation of any specific area is aided by the many detailed references,

With 56 pages of references and both a geographic/subject and an author index, this is a good source book for further exploration of igneous petrogenesis. My one complaint would be that the print was rather too small to read easily for any length of time.

Linda Lane Thornton MA, continuing Earth Sciences student

Classic Landforms of the Burren Karst by David Drew, 2001, Geographical Association, 50pp, £8.95 (paperback) ISBN 1899085912.
Visiting the Burren Karst landscape in the west of Ireland is a geological must. If you intend visiting the area you should take this 50 page Guide with you. It is well presented in full colour with a liberal sprinkling of photographs and easily understood relevant maps and diagrams.

The subject matter is very readable and is divided into convenient sections: the general geology, the area hydrology and a section dealing with cave formation. The differences in limestone units and their influence on topography is mentioned, including the formation of pavements and the effect of weathering and glaciation. The hydrology includes sinkholes, underground and surface streams and seasonal lakes. Some cave systems are examined and the controls on their formation discussed. As well as a specific Glossary, there are the usual map references for the features described.

Although this Guide is specifically for the Burren Karst, much of the content would apply in general to any karst area.

John Wade BSc Hons (Open)

Fieldwork Ideas in Action by Gill Miller, 2000, London, Hodder and Stoughton, 106pp, £40.00 (paperback) ISBN 0340753552.
This field-work guide for specific projects or studies is a welcome addition to the existing literature on the subject. After brief introductory sections on organising fieldwork for a project and advice on writing up the study, the book considers 43 different study topics and examines each one in some depth. A brief geographical background is suggested for each study, then advice is given on what primary and secondary data to collect and how it might be analysed. Suggestions of appropriate resources are given and some techniques are explained in detail with some given worked examples.

This ring-bound text will be of enormous use to busy teachers. All geography staff have to find time to discuss projects with students on an individual basis and the sensible use of this book should reduce the length of these sessions. Once a topic has been chosen, the student can be referred to this text for initial ideas on data collection, which can be refined at a later stage. Most of the standard topics for projects are found within this text, although one might have hoped for the inclusion of more ecological studies, since these are ones where primary data collection is relatively straightforward and deserve a wider take-up amongst students. For each topic the advice given is exhaustive and, if students were to follow this up conscientiously, a high grade in the project would result. Even if a student's chosen topic is not included within this text (and many will be excluded) the advice on data collection is often transferable from one topic to another.

Some human project topics are notoriously difficult to carry out, particularly if they are over-reliant on questionnaires. Good advice is given on questionnares in the introduction, but one wonders just how realistic it is to suggest to students that they should complete 200 questionnaires in a study (impact of a supermarket on the local environment). One might question how useful a study looking at the application of urban land use models to a local town might be. An enormous amount of time might be spent on transects, and other data collection exercises, that lead to the rather negative conclusion that no model is appropriate! Some of the detailed advice in the individual topics is perhaps unrealistic in what students might be expected to achieve, e.g. "Assess the impact of EU policies on a farm". This seems to be asking too much of the average student, since it is far too complex.

Minor quibbles apart, this should be a very useful book for both teachers and students at A Level. It should find its way onto the shelves of every geography department but its price may be a deterrent to some.

John Chaffey

Uplift, Erosion and Stability: Perspectives on Long-term Landscape Development by B J Smith, W B Whalley & P A Wark (eds), 1999, Geological Society, London, Special Publication, 162. 278pp, £65.00 (hardback) ISBN 1862390479.
This book is a Special Publication of the Geological Society and consists of nineteen papers about the interrelationship of geological processes and gemorphological expression. The papers examine various processes, with its gemorphological expression, from a range of locations across the world, starting in the UK then moving to places as varied as the mountains of China, African deserts, the Americas and Antarctica's cold deserts. The aim of the book is to bring together geologists and geomorphologists to use their expertise in each field to further the understanding of the processes and controlling mechanisms of uplift, erosion and stability of a landscape. Once the geological framework of a landscape has been established constraints can then be placed on the amount and rates of these processes.

It is not possible to review all the papers in the space allowed so I selected some that develop field examples of concepts taught in the various OU courses. All of the papers are well illustrated with diagrams, maps, photographs and satellite images. The general format begins with an abstract, introduction, research data, discussion, conclusions and implications, and ends with excellent references. It was surprising, however, not to find a glossary (something I would have found very useful), especially as the papers' aim is to encourage an interdisciplinary approach to the topic.

The paper "Influence of crustal movements on landforms, erosion and sediment deposition in the Irangi Hills, central Tanzania" by Mats G. Eriksson, discusses disruption of rivers by faults in the Kondoa Irangi Hills. The rivers, faults and sand deposits were mapped from maps, aerial photographs and satellite images. From the resulting map, individual tectonic blocks are clearly visible. Cores were taken from lakes that developed where rivers are disrupted by faults. Once dated the sedimentation and denudation rates can be calculated for the catchment area.

The application of palaeolandsurface analysis to the study of recent tectonics on central Italy by R Basili, F Galadini & P Messina is a study of the Pliocene and Quaternary intermontane basins. By reconstructing palaeolandsurfaces, basin development and rates of uplift and erosion can be determined. Strath terraces on the basin walls were mapped and dated to assess the relative activity on the various faults, giving a good indication of the most active.

There is a chapter on the structural and stratigraphic perspectives on the uplift and erosional history of Djebel Cherichira and Oued Grigema, a segment of the Tunisian Atlas thrust front by A W Baird & A J Russel. This paper is full of complex thrust structures the basic concept of which will be familiar to OU students. Hanging wall, footwall flat, hinge line it is all there but with the complications of a field situation. A wealth of familiar diagrams makes this paper interesting and the arguments easy to follow. A must for structural geologists.

The other papers are very interesting, some are challenging but there are new ideas and ways of using and extending concepts learned in OU studies. At £65 it is expensive but well worth reading.

Lyn Relph BSc(Hons) U.C.N.W (Bangor), Continuing ES student

Italian Volcanoes by Chris Kilburn and Bill McGuire, 2001, Terra Publishing, 166 pp, £11.95 (paperback) ISBN 1903544041.

This affordable volume is one of the Classic Geology in Europe series from Terra Publishing and the first sentence of the Preface says it all – "This book began as a guide to Italy's active volcanoes and finished as a guide and a practical introduction to volcanology". Combine the informal but 'better than a guide book' style of presentation with decades of experience on Italy's active volcanoes by the authors, Chris Kilburn and Bill McGuire, both of University College London, and you get an ideal complement to the OU way of learning.

Chapter 1 sets the scene with an overview of the tectonic settings, followed by sections on the nature of Italian magmas, styles of eruptions and chemistry. It concludes with a very important safety guide as dozens of observers of active Italian volcanoes have been killed by their activity in the last decade or so.

Chapter 2 explores Somma-Vesuvius. Its evolution and eruptive history are described, along with descriptions of three classic eruptions in AD 79, 1631 and 1944, including the destruction and rediscovery of Pompeii and Herculaneum. There are sections on rock chemistry and petrography, its magmatic system and the future.

Chapter 3 deals in a similar way with Campi Flegrei, the Phlegraean Fields. Chapter 4 details the Aeolian Islands, north of Sicily: Vulcano, Stomboli, Lipari and Panarea each get their own section.

The longest chapter in the book is Chapter 5 about Europe's largest volcano, Etna, which attracts so much attention from researchers and interested observers.

Each chapter contains detailed itineraries that have been specially chosen to highlight the wide spectrum of volcanic products, how these volcanoes work and their danger to local people. Other localities are described, allowing additional do-it-yourself excursions. The style of writing is such that there are no references, just suggestions for further reading and web sites for up-to-date information. A nice five page glossary included several terms new to me.

Italian volcanoes have been the longest studied of any in the world and have given us generic terms like "Plinian eruption" and "Strombolian activity". More than ever, they are easy to get to and thoroughly rewarding and exciting to visit. This volume is a useful study guide to second and third level volcanism as well as being a super guide book to the cradle of the study of the Italian volcanoes.

David Maddocks BSc Hons (Open), BA (Open)